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Electrical Cable Harness Tester

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Senior Capstone Project Report

Electrical Cable Harness Tester

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Section 1: Acknowledgements

Section 1.1 Acknowledgements

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Section 2: Abstract

Section 2.1 Abstract

The purpose of this document is to outline the design process and our final design solution created to address the problem statement. This report will include the initial problem statement, design requirements, conceptual designs, and the details of the final design. The intention of this project is to create a more effective method to verifying the correct configuration of cable harness's being used with Parker Hannifin equipment. The device should be semi-automated with minimal user interaction and it must meet the requirements set forth by Parker Hannifin. Our conclusion is that the presented detailed design can meet all of the specified functional requirements and constraints.

Section 3: Problem Statement

Section 3.1 Problem Statement

The Parker Hannifin Precision Cooling Business Unit uses custom-designed cable harnesses in their product line. The quality of these harnesses must be monitored. In particular, the continuity of a harness between two corresponding terminals must be verified. Currently, the tests of harnesses are conducted manually, which (1) take an extremely long time and (2) partially depend on visual inspection and subjective judgment. The company requests the senior design group to come up with a semi-automated testing system so that the problems with manual tests are solved in the testing process.

The senior design project is to solve the aforementioned problems by developing a semi-automated testing workstation. The continuity of a cable harness will be tested automatically and an operator will be notified of any irregularities. The device should be designed so wear on harnesses, connectors, and the tooling involved is minimized. Parker also requires the construction and programming of the system to be completed. The harness testing system will be applied in the production of their Precision Cooling products and systems.

Section 3.2 Requirements

Parker Hannifin has provided guidance to the group on some specific aspects and features of application they would like to see regarding the capabilities of the cable harness tester. The senior design group will seek to meet and exceed these quantified expectations. The requirements and specifications are as follows:

- Testing of defects – The tester workstation should be able to detect open or crossed connections.
- Ease of use – An operator who has never used the machine should be able to learn how to use it in less than (30) minutes. This will expedite the implementation of the system designed by the group into the production process.
- Semi-automation speed – Time between testing two harnesses with the same part number should be no more than (20) seconds. This will ensure that part turnover is high and will greatly improve upon the throughput of the current process.
- Tooling changeover – Time between testing two harnesses with different part numbers should be no more than (5) minutes.
- Design flexibility – Tester should accommodate harnesses with up to (20) conductors. This will allow for a lot of flexibility in future harness designs.

Section 3.3 Design Parameters

Certain parameters of the system are given. These parameters have been specified by Parker based on their current needs. During all stages of the design formulation and implementation, the constraints for these parameters must be satisfied.

The following are the given design parameters of the system:

- Current harnesses to be tested – The tester must account for all current cable harnesses used by Precision Cooling. The tester may accommodate more part numbers in the future, but as a minimum must accommodate the current part numbers.

  The following are the part numbers for the harnesses used in Parker systems:

  PCC-WH-00001

  PCC-WH-00002

  PCC-WH-00003

  PCC-SY-021

- Terminals and plugs – Common terminals and plugs are used in the harnesses used for Precision Cooling systems. Accounting for the all terminals and plugs families used within current systems will improve versatility if new harnesses require testing.

Plug Families:

AMP

Junior Power Timer

Junior Timer

Tyco

Mini-Universal MATE-N-LOK

Molex

Mini-Fit-Jr

Mini-Fit® Jr™ 5557

Terminal Families:

AMP

Junior Power Timer

Timer

Tyco

Mini-Universal MATE-N-LOK

Molex

Mini-Fit® Jr™ 5556

- One operator – Efficiency is a very important consideration to Parker. The semi-automated nature of the system requires only one operator to run this system. Decreasing the amount of manpower need to operate the system will increase efficiency.
- Lot testing – Cable harnesses purchased by Precision Cooling are made to print specifications. The harness manufacturers test crimp height and strength to verify the terminals and conductors are structurally sound. Since many of the operations used to make the harnesses are semi-automated or fully automated, less concern is placed on the correctness of individual harnesses. More concern is placed the correctness of the harnesses as a whole. Testing 10% of the harnesses in a lot will be sufficient to verify the process used to make them is correct.

Section 3.4 Design Variables

Meeting the given requirements and specifications is necessary for a design, so is to have some design variables that one could alter during the process of design. These variables give some flexibility to the design of the system. For this project the design variables can be separated into two distinct areas: Electrical and Mechanical.

The design variables for the electrical components focus on the actual continuity and isolation checks that are required of this design. Electrical aspects could also be implemented within any type of motion control if the design calls for it. The design variables for mechanical components will include the mating of the connections and device mounting including an enclosure. More specifically,

- ❖ Mechanical Components
    - Enclosure – This is the aspect of the design that will contain the control system and place any type of interface at an appropriate height.
    - Mating Connection – The point at which the connectors from the cable harness are mated to the system.
    - Mechanical Drive Components – This is the aspect of the design that mate the cable harness connections to the system
- ❖ Electrical Components
    - Control System- The system that will be chosen to run the testing is variable and will be determined based upon ease of operation and what fits best with the requirements and specifications. This system will choose the programming type that will be used to perform the given task.
    - Electrical Automation Devices– Depending upon how the connections will be mated to the system will determine the need for any type of electrical devices used in the process.
    - Power – Main voltage supply that the system will operate from. This can be determined based upon which control system is chosen and if any electrical automation is utilized in the design.

Section 3.5 Limitations and Constraints

Limitations and constraints are restrictions of the system. The system to be designed has constraints that are required from Parker. Each limitation is set in order to narrow the parameters of the system. The following are the limitations and constraints for the system:

- Size – The system must take up no more than 15 square feet overall floor dimensions. This is a standard area for a small system like to occupy. System must be ergonomically designed; it implied that it should be comfortable for any standing operator to use.
- Cost – The overall total cost is set loosely at $15,000. Parker wants us to create our system with coast in mind. They are aware that a number of advanced parts and software may be integrated into our system, making the total cost exceed the limit.

- Safety – Our system must incorporate safety features to prevent injury from mechanical and electrical components. We intend to design our system in such a way that all moving parts are covered, and we intend to incorporate control device that will limit user accessibility to the system while it is at the running condition. Also the voltage through the system will be in the safe range to human operators.
- No damage to harnesses – System must not visibly deform the harnesses or terminals in any way. Moreover, the system must be able to test without destroying or ruining what is being tested.
- Adding part numbers – The system should accommodate the addition of new harness configurations. Parker requires that the system be able to test a number of existing cable harnesses that they are currently using and have the capability of testing future cable harnesses. The system must be designed in such a way that it may be adjusted for future cable harnesses.

Section 3.6 Other Considerations

The following are design considerations not mentioned above. The conceptual design will utilize these even though they were not specifically required.

- In-source procurement – Parker Hannifin can supply us with a wide variety of motion and system control components. We will utilize as many Parker Hannifin components as possible in the design of the test workstation.
- Modular design – The division of Parker Hannifin that will be using our device is a growing division and has a limited number of cable harnesses as of today. The system will accommodate the addition of different configurations of cable harnesses.
- Tooling life – Minimal wear should be incurred on mating surfaces. Care will be taken when choosing materials within our device to extend the life of the device as long as possible.
- Ergonomic – Attention should be given to minimize stress and discomfort felt by operator. A comfortable height will be used to reduce overall stress imposed on the operator. The position of the harness when inserted will be oriented in such a way to reduce the chance of injury to the operator.
- Scanning – The selection of the test program will be initialized by scanning a bar code on the harness being tested. This feature will only be utilized if the budget allows.
- Diagnosis of irregularities – An explanation of the type of deficiency will be displayed for the operator if a deficiency is found. The device will also print an error report if the budget allows.

Section 4: Conceptual Designs

Section 4.1 Conceptual Designs

Modular architecture is used for the design of test workstation. The system level test functions will be fulfilled through the use of five design parts: Pins, pin configuration, pin array motion, plug fixture, and a controller. The group brainstormed conceptual designs for each of these components and ended up with a number of concepts that satisfied the requirements set forth in the problem statement. These conceptual options of these components are as follows:

- Pins
    - Rigid pin
    - Spring used as pin
    - Spring-loaded pin
- Pin configuration
    - Adjustable pin array
    - Fixed pin array
- Pin array motion
    - Rack and pinion
    - Servo with arm
    - Servo with screw
    - Linear actuator
- Plug fixture
    - Clamping without spacers
    - Clamping with spacers
    - Strapping with spacers
    - Click-in fixture
- Controller
    - Allen-Bradley SLC 5/02
    - Allen-Bradley MicroLogix 1000
    - Siemens Simatic S7-1200 PLC
    - Microchip Microcontroller
    - Raspberry Pi
    - Arduino Microcontroller

The conceptual designs for each component of the cable tester are described in detail in the proceeding sections of this report.

Section 4.2 Conceptual Designs Pins

An interface between the harness being tested and the testing hardware is necessary to complete the testing. The interface must make sufficient contact with the terminal to complete the testing circuit, and have enough tolerance not to damage the harness terminals. This interface will be created using a moveable array of pins. Three different conceptual designs are generated for the pins.

Section 4.2.1 Rigid Pins

Rigid pins are a straightforward approach. Pins made of an electrically conductive material are fastened in an array to make connections with terminals being tested. Figure 1 illustrates this design.

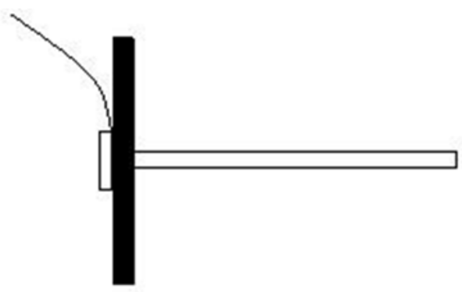

Figure 1: Representation of Rigid Pin

Section 4.2.2 Springs as Pins

Springs configured in an array make connections to the terminals on the plugs. The spring would need to be made of an electrically conductive material. A representation of this design is shown in Figure 2, below.

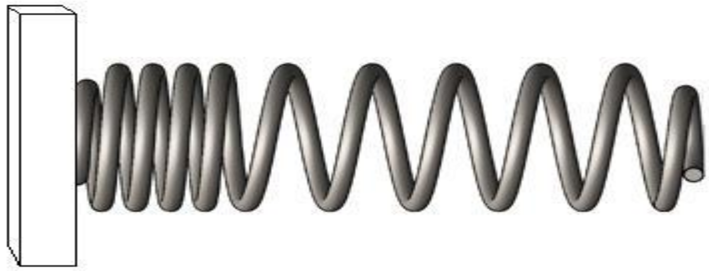

Figure 2: Representation of Electrically Conductive Spring (Adapted from www.armoredworks.com)

Section 4.2.3 Spring-loaded Pins

Spring loaded pins consist of a pin, a spring, and another piece for support and alignment. This configuration is shown in Figure 3. The pin and the spring are made of an electrically conductive material, while each pin would need to be electrically isolated from all the others.

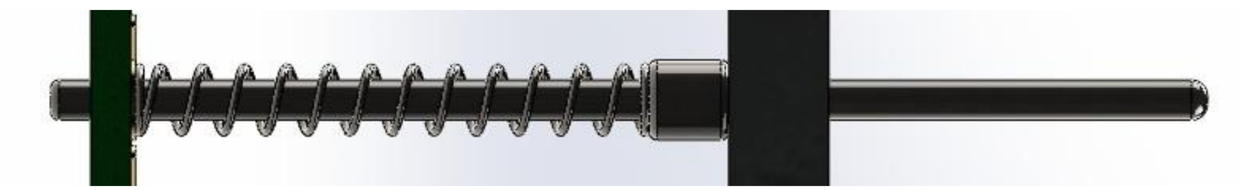

Figure 3: Rendering of spring-loaded pin

Section 4.3 Conceptual Design Pin Configuration

The pin configuration refers to the spacing and function of the conductor pins in our testing device. The plugs in the cable harnesses being tested have three different pin spacing dimensions. This section discusses the different design options that can overcome this design challenge.

Section 4.3.1 Adjustable Pin Array

The adjustable pin array is a set of pins attached to a scissor link assembly shown in Figure 4. The spacing between the pins can be adjusted with one actuating device at a fixed location.

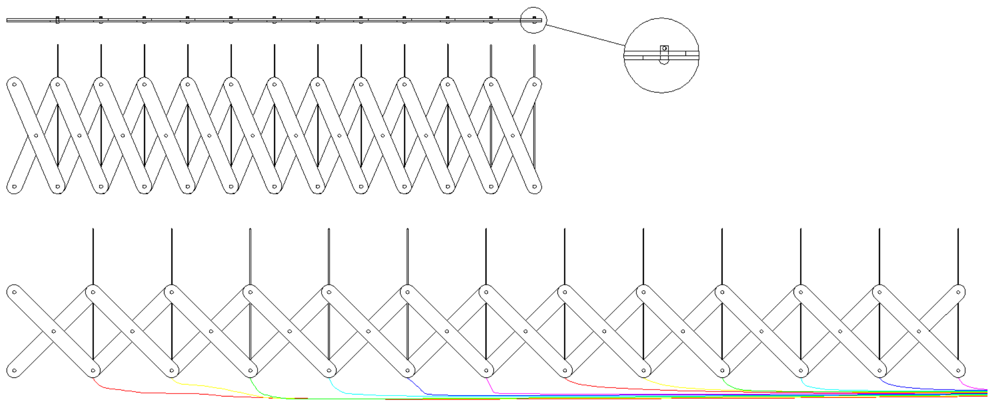

Figure 4: Adjustable Pin Array

Section 4.3.2 Fixed Pin Array

The pins designed will be arranged in a set configuration that cannot be changed. This will require multiple sections of the machine to accommodate plugs with different terminal spacing. Figure 5, below, displays this concept.

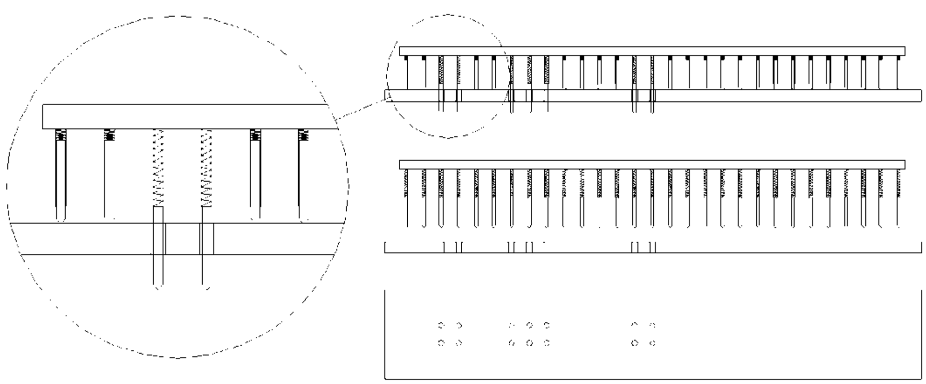

Figure 5: Card Pin Configuration

Section 4.4 Conceptual Design Plug Fixture

The plugs at the end of each cable must be inserted into the cable tester in exact locations for testing. The plugs on cables will naturally curl or twist making them difficult to place in an exact location. To insure a successful test, it is necessary to fix the plugs being tested. The plug will be given a force from the pin when tested. The plug needs to be able to resist this force and remain in contact with the pin to allow the testing to be completed. The cable tester is required to test multiple plugs in one test. A device to align as well as fix the location of each plug must be included in the cable tester to accommodate these requirements. The device should not damage the plugs in any way as is a specific requirement from parker. The device needs to be easy and fast to use or operate. The group generated four different designs, for a fixture, that could be used in the cable tester.

Section 4.4.1 Fixing Plugs by Clamping

The design for fixing the cable harness plugs by clamping is shown in Figure 6. This design squeezes the plug locking it in place. The plug needs to be held in place by the operator until the clamp is closed onto the plugs. The difficulty of this would increase depending on the number of plugs being clamped. Consequently the time to operate the plug fixture would greatly increase if the number of plugs increased. Alignment of each plug will not be exact. Plugs inserted in this design will have alignment issues. Alignment would need to be made by a separate device or by making adjustments to the design. This design was chosen to be compared to the other designs because of its simplicity and low cost.

The connector clamp design is fairly flexible, but will only work for like plugs. A small plug will not be fixed well in the same connector as a large plug. This design requires no springs to fix the plugs. This lowers the cost and complexity. This design is a base model that could be improved upon in order to achieve desired specifications and requirements

Figure 6: Connector Clamp

Section 4.4.2 Fixing Plugs by Clamping with Spacers

The design for fixing the cable harness plugs by clamping with spacers is shown in Figure 7. This design was chosen to be compared to the other designs because it is an improvement to the clamp design. Plugs can be placed in the clamp easily with spacers, and the spacers will hold the plug in place. Positioning plugs in exact locations is easily achieved with the spacers. The spacers can be adjustable increasing flexibility to the design. Alignment should be checked but may not need to be made by a separate device.

This design is limited in the same way as the original as to how the size of plugs needs to be similar or the fixing of the plugs will not be possible. Further adjustments could accommodate for this. This design needs no springs to fix the plugs. The cost to build this design will be increased from the original design due to the addition of the spacers as well as additional machining.

Figure 7: Connector Clamp with Spacers

Section 4.4.3 Fixing Plugs by Strapping with Spacers

The design for fixing the cable harness plugs by strapping with spacers is shown in Figure 8. This design was chosen to be compared to the other designs because it is an improvement to the clamp design. The strap material will be flexible, and fixing plugs with unusual shapes or fins can be achieved without damage to them. The spacers can be adjustable. The spacers will help in aligning the plugs in exact positions. The force applied to plugs from the strap may affect the alignment. Alignment should be checked but may not need to be made by a separate device.

Fixing multiple plugs with large size differences, with this design, may not be achieved with this design, although the design can accommodate for small size differences much easier than the previous designs. A spring could be added to the design to make the strap retractable. Forces from the strap may add a small rotation to plugs that are improperly inserted causing alignment issues. The strap and other parts could increase the cost.

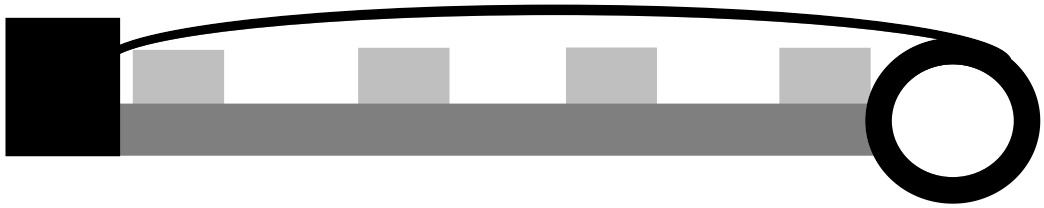

Figure 8: Connector Strap with Spacers

Section 4.4.3 Fixing Plugs by Clicking

The design for fixing the cable harness plugs by strapping with spacers is shown in Figure 9. The plugs will be individually inserted into a clicking device locking that plug in place. This process takes the least time to complete out of all the other designs. The plugs will be aligned with the most accuracy out of all the other designs. Thin padding can be added to minimize damage to the plugs. Springs added will determine the amount of force applied to the plugs. This design could include ejection of the cable after test completion decreasing operator involvement as well as overall testing time.

Each plug will have its own clicking device that could be adjustable in multiple ways to accommodate for a large size difference in plugs. This allows plugs with a large size difference to be tested at the same time. The cost of this design will be much larger than the others due to the amount of machining and the addition of springs. This design requires numerous devices to be included in the final cable tester design.

Figure 9: Clicking Device

Section 4.5 Conceptual Design Pin Array Motion

The pin array will need to move in and out of the plug during the testing procedure. The linear motion of the pin array will be accomplished with one of the following devices: rack and pinion, rotary servo with link/slider, rotary servo powered screw, or a linear actuator shown in Figure 10. The four devices are relatively simple to implement, so all four were analyzed further. The rack and pinion uses a small pinion gear attached to a servo motor. That gear meshes with a rack. The crank slider has a crank attached to the servo on one end and the slider on the other. The servo powered screw has a screw attached to the servo and a collar moves on the screw as it is turned. The linear actuator is a device that can be purchased to cause a linear motion directly.

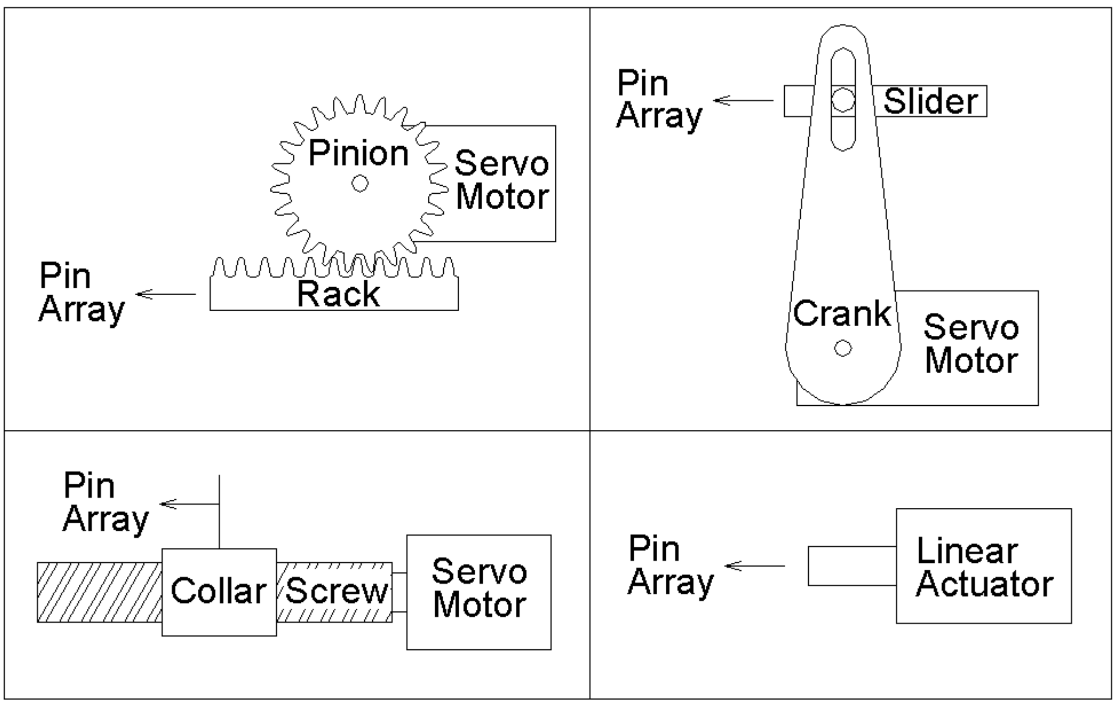

Figure 10: Representations of linear motion devices

Section 4.6 Conceptual Design Controller

The controller is what is used to operate the testing functions of the test system. It will also be utilized for motion control, any type of transducer input, as well as communicating with the user interface. A programmable logic controller (PLC) is used for automation of machines in many different industries. These controllers can have multiple input and output arrangements, motor control modules, and network modules. PLC's are resistive towards electrical noise, vibrations, and impact which make them ideal for industrial applications.

Microcontrollers are small computers contained in a single integrated circuit. These can be used for automated controlled products such as engine control systems, remote controls, appliances and motion control. These controllers utilize machine code for programming although compilers and assemblers can be used to convert high level assembly languages such as C to compact machine code for ease of programming. They usual contain dozens of general purpose pins which are software configurable for either inputs reading sensors or outputs for driving devices such as LEDs or motors.

Section 4.6.1 Allen Bradley Programmable Logic Controller

Allen Bradley is a well-known PLC manufacturer that has many years of experience with industry proven controllers. There are two possible Allen Bradley PLCs that have been determined for possible use. Both of these units utilize the same easy to use software that is already in place at Parker for some of their other equipment.   The MicroLogix 1000 offers many features of a larger PLC in a very small footprint. The tradeoff for the smaller size is a set number of inputs and outputs. Since this maximum number offered is thirty two inputs or outputs, the MicroLogix 1000 does not meet the requirement of 20 conductors, with provisions for 20 additional conductors. The SLC 5/02 uses input output cards in a chassis, which increases its flexibility. Chassis are available with 13 I/O slots.   Since each I/O card can contain as many as 32 inputs or outputs, a theoretical 416 I/O positions are available. Specialized I/O cards including motor control outputs are available. Furthermore, the SLC 5/02 meets all of the requirements and specifications it making it a viable option.

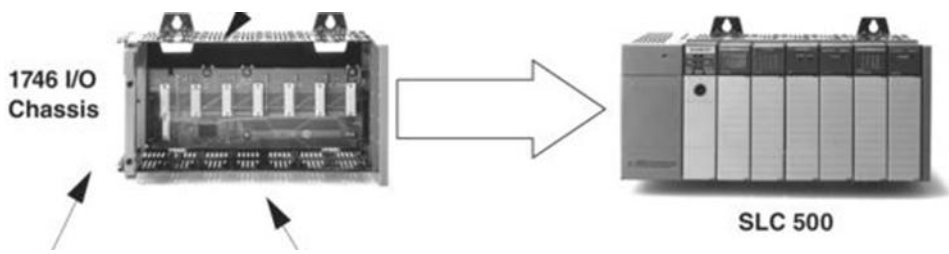

Figure 11: Allen Bradley SLC 5/02 (Adapted from www.ab.com)

Figure 12: Allen Bradley MicroLogix 1000 (Adapted from www.ab.com)

Section 4.6.2 Siemens Simatic S7-1200

Siemens has been in the industry for many years with their line of PLC's as well. The Simatic S7-1200 offers great flexibility much like the SLC 5/02. This system even offers the ability to control it from a smart phone by downloading their app. The downfall of this PLC is it utilizes different software than what Parker uses. This becomes a major factor in deciding which control system will be implements into the system since having to learn new software to program the system would change the ease of use.

Figure 13: Siemens Simatic S7-1200 PLC (Adapted from www.automation.siemens.com)

Section 4.6.3 Microchip Microcontroller

Microchip is a well-known and trusted manufacturer of microcontrollers founded in 1987. Microchip microcontrollers are highly tested and industry proven to be extremely effective for manufactured products and hobby projects alike. They provide more than enough available I/O pins and with additional memory provisions, can handle any required memory specifications. While all the specifications and requirements for the harness tester can easily be met, programming and reprogramming a microcontroller requires more specialized skills than programming a PLC. Parker has dealt with PLC programming before, while they have not programmed microcontrollers. If a microcontroller is implemented, extra cost time and cost will be incurred.

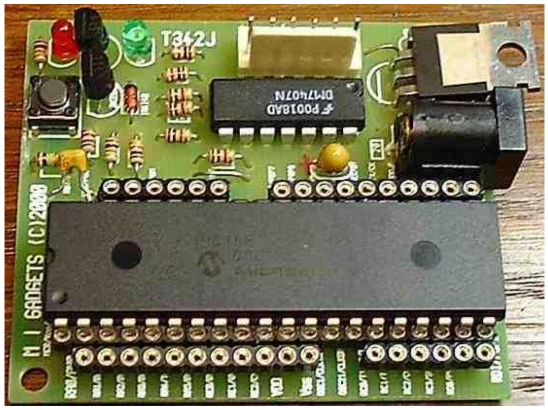

Figure 14: Microchip Microcontroller (Adapted from http://web.singnet.com.sg/~migadget/T342.h)

Section 4.6.4 Raspberry Pi

Raspberry Pi is a credit card sized single board computer created with the intention of teaching basic computer science. A Raspberry Pi would meet all of our requirements and specifications, but is not industry proven. Because it is such a new product, reliability and life expectancy is unknown. Another concern is lead time. The current lead time is very high since this new product is in such high demand. Due to these concerns, a Microchip Microcontroller is a better option.

Figure 15: Raspberry Pi Single-Board Computer (Adapted from http://en.wikipedia.org/wiki/Raspberry_pi)

Section 4.6.5 Arduino Microcontroller

Arduino microcontrollers provide open source flexibility at a low price. The software, as well as the hardware, are open source and therefore more user friendly and require less programming background to use. Unfortunately, the number of I/O pins is very limited at 54. Since each conductor will need an input and an output for proper testing, this limits the maximum conducts to 27. One of our requirements is to make provisions to accept up to 40 conductors; the Arduino will not meet this requirement.

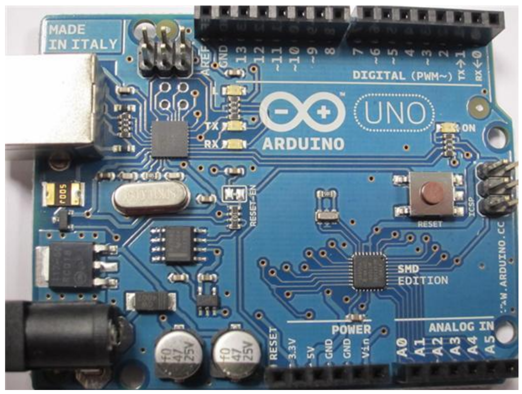

Figure 16: Arduino Microcontroller (Adapted from http://www.mouser.com)

Section 5: Evaluation

Section 5.1 Evaluation of the Conceptual Designs

A decision matrix has been created for each concept, evaluating the possible solutions. Criteria, based on requirements and specifications, were chosen to identify strengths and weaknesses of each design. Each was given a weight from (0 to 100) that denotes the importance of the criteria. The more important a criterion is, the higher the number it receives. Each design received a score from (0 to 10) to denote how well it conformed to the criteria A higher score denotes the design better complies with the requirement. . If criteria were not applicable to the design, it was noted in the score and weighted score section. Listed below, in order of importance, are the criteria used. Weighting factors are parenthesized.

- Safety (100) – Does the design promote safe operation?
- Design Flexibility (95) – Is the design adaptable to the addition of conductors?
- Minimum damage to Harness (90) – Does the design prevent damage to harnesses?
- Speed (85) – Will the design promote timely operation of the tester
- Adding Part Numbers / Memory Capacity (85) – Can new part numbers easily be added?
- Reliability (80) – Will the design function be as expected consistently?
- Life Expectancy (75) – Will the design have a long operational life?
- Ease of Use (75) – Does the design promote timely operation of the tester?
- Ease of Procurement (70) – Will the design be easily attained or built?
- Changeover Time (65) - Is assembly/repair time kept to a minimum?
- Ease of Assembly / Repair (55) – Is assembly/repair time kept to a minimum?
- Cost (50) – Will the design increase our flexible budget?
- Aesthetics (30) – Does the design improve the overall appearance of the tester

Section 5.2 Evaluation of Pin Concepts

An interface between the harness being tested and the testing hardware is necessary to complete the testing. The interface must make sufficient contact with the terminal to complete the testing circuit, and have enough tolerance not to damage the harness terminals.

Section 5.2.1 Evaluation of Rigid Pins

Pins with rigid construction are a straightforward approach to making electrical connections. Pins of various sizes can be purchased and easily installed in an array. While this design adds simplicity and low cost, it also adds a greater chance of pinching and damaging terminals and plugs. Figure 1 illustrates this design.

Advantages:

- Relatively inexpensive
  - No cost of delicate springs
  - Less material used
- Simple to design, assemble, and replace
  - Rigid fasteners
  - One piece per pin rather than several
- Easily integrated into custom-made fixtures

Disadvantages:

- Higher chance of damaging terminals on cable harnesses
- Higher chance of bending a misaligned pin
- Injuries could occur from pinching

Considerations:

- Minimize length as much as possible
- Deal with safety concerns

Section 5.2.2 Evaluation of Springs Used as Pins

If this design is chosen, electrically conductive springs will be used in the place of springs. Springs are commonly used to make electrical connections, but using them in an application such as the one laid out in our problem statement is a somewhat novel approach. For this reason, implementation of this concept would require quite a bit of detailed design work. There are no readily available designs from outside sources. Springs would cause minimal wear to terminals, but deflection of the springs in the vertical direction could lead to complications. A representation of this design is shown in Figure 2.

Advantages:

- Low chance of damaging plugs and terminals
    - Deflection is immediate and responsive
- Low complication
    - Few parts to wear out

Disadvantages:

- Lots of design work required
    - Concept is not well-developed or available from outside sources
- Deflection of springs in non-linear directions could cause errors and complications

Considerations:

- Balance length for minimum compression force and maximum rigidity

Section 5.2.3 Evaluation of Spring-loaded Pins

Spring-loaded pins combine the best features of rigid pins and electrically conductive springs. They have the precision of rigid pins, while they protect the electrical cable harnesses and the tester itself by deflecting when contacted. While the design of is more complicated, spring-loaded pins are a well-developed technology and many designs are readily available for purchase at a fairly low cost. This configuration is shown in Figure 3.

Advantages:

- Minimize wear to plugs, terminals, and pin itself
- Minimize chance of damage to plug if misaligned
- Hardware is readily available for low noise electrical connections

Disadvantages:

- Slightly higher cost relative to other options
- Higher complication than rigid pins
- Purchased designs are somewhat inflexible from a design standpoint

Considerations:

- Improve serviceability in design

Section 5.2.4 Decision Matrix

It can be seen in Table 1 that after quantitative weighting and rating was completed, the spring-loaded pin design scored the highest with a score of 5230 and the rigid pin concept was second with a score of 5115. The spring-loaded pin concept scored well on safety, reliability, and minimum damage to harnesses. The concept for springs used as pins got an overall score of 4775. It did not score well on life expectancy, design flexibility, or ease of assembly/repair. The rigid pin concept had average scores overall, but there were concerns with safety and damage to tested parts.

Table 1: Decision Matrix, pin design selection

		Rigid Pin		Spring Used as Pin		Spring Loaded Pin	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**	**Score**	**Weighted**
Safety	100	7	700	8	800	9	900
Design Flexibility	95	8	760	6	570	6	570
Minimum Damage to Harness	90	6	540	9	810	10	900
Reliability	80	10	800	8	640	9	720
Life Expectancy	75	9	675	6	450	8	600
Ease of Procurement	70	8	560	8	560	8	560
Ease of Assembly / Repair	55	8	440	7	385	8	440
Cost	50	8	400	7	350	6	300
Aesthetics	30	8	240	7	210	8	240
Total			5115		4775		5230

Section 5.3 Evaluation of Pin Array Concepts

In comparing plug configurations, the group took into account the number of inputs and outputs required by the controller. A fixed pin configuration would require more pins, and inputs and outputs on our controller. Also taken into consideration were the time constraints on the project. The development of an adjustable pin array would require a lot of design and prototyping.

Section 5.3.1 Evaluation of Adjustable Pin Array

The adjustable pin array is a set of pins attached to a scissor link assembly. The spacing between the pins can be adjusted with one actuating device at a fixed location. Incorporating this design into our final assembly would increase the flexibility of our device making it able to test plugs with different pin spacing. This function is not a requirement but would add value to our device. A simple example can be seen in Figure 4.

Advantages:

- Fewer inputs and outputs required in the PLC or Microcontroller
- There will be fewer over all places the cable ends will be attached
- Will require fewer pins
- Two actuators will be needed to accomplish adjustment

Disadvantages:

- Motion of pins will require a lot of small moving parts
- Tolerance will be very small for pins to align
- This is a complex system with a lot of moving parts

Considerations:

- Additional programming will be needed

Section 5.3.2 Evaluation of Fixed Pin Array

The fixed pin array is a simple fixed configuration of pins. The pins would not be able move independent of each other. This configuration is less complex and would meet all the requirements in the problem statement.

A device that was considered that could be implemented in either of the previously mentioned components is a pin configuration card shown in Figure 5. This simple device is rigid card with the pin configuration being tested drilled out of the material. The pins being used would protrude through the holes and the ones not being used would contact the card and compress the internal spring not allowing the pin to contact anything past the card.

Advantages:

- Less motion is required in the pins
- Fewer moving parts
- Less cost

Disadvantages:

- Requires a lot of inputs and outputs to the PLC or microcontroller
- Requires a technician to make new cards when a new cable configuration is created
- Adds additional complexity for the operator if they are required to change the cards

Considerations:

- Longer lead time
- Complex to create the card
- Material will need to be chosen so it will not wear out too fast

Section 5.4.3 Decision Matrix

The decision matrix compares the adjustable pin array with and without a pin configuration card as well as the fixed pin array with and without a pin configuration card. The adjustable pin configuration adds a substantial amount of complexity. Its final score is 5590. The fixed pin configuration has a final score of 6555. The pin configuration card only lowers the score of either the fixed or adjustable pin array. The only area where the card would be beneficial is in the area of possible damage to the harness. The idea is that the card would align the pin more accurately.

Table 2: Decision Matrix, Pin Configuration

		Adjustable w/o card		Adjustable with card		Fixed w/o card		Fixed with card	
Criteria	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Safety	100	8	800	8	800	8	800	8	800
Design Flexibility	95	6	570	5	475	8	760	7	665
Minimum Damage to Harness	90	8	720	9	810	8	720	9	810
Adding Part Numbers	85	10	850	9	765	6	510	5	425
Reliability	80	7	560	6	480	10	800	9	720
Life Expectancy	75	7	525	6	450	10	750	9	675
Ease of Procurement	70	6	420	5	350	7	490	6	420
Changeover Time	65	8	520	7	455	10	650	9	585
Ease of Assembly / Repair	55	3	165	2	110	9	495	8	440
Cost	50	5	250	4	200	8	400	7	350
Aesthetics	30	7	210	7	210	6	180	6	180
Total		5590		5105		6555		6070	

Section 5.4 Evaluation of Array Motion

Section 5.4.1 Decision Matrix

The linear actuator had the highest score in the decision matrix (3720). This device is the most simple of the four choices. Cost is the only place the linear actuator falls short. Even though it is more expensive than the other choices it will not be so expensive that it will jeopardize our overall budget. The rack and pinion and crank slider options tie for second. Both of these options scored 3490 and are both reasonable options. Both options add moving parts and complexity. The screw had the lowest score of 3135. This is mostly due to the slower speed and addition of another part.

Table 3: Decision Matrix, pin array motion

		Rack and pinion		Servo with arm		Servo with screw		Linear actuator	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Speed	85	10	850	10	850	8	680	10	850
Reliability	80	8	640	8	640	7	560	9	720
Life Expectancy	75	8	600	8	600	8	600	9	675
Ease of Procurement	70	8	560	8	560	8	560	9	630
Ease of Assembly / Repair	55	8	440	8	440	7	385	9	495
Cost	50	8	400	8	400	7	350	7	350
Total			3490		3490		3135		3720

Section 5.5 Evaluation of Plug Fixture

The cable harness plug fixture is necessary to successfully complete a test of a cable. The plug fixture section of the cable tester is the area where the operator will be interacting with the cable tester. There is chance of injury to the operator as well as damage to the plugs at this section of the cable tester. To determine the best possible plug fixture design the most important criteria needed to be considered is safety and minimal damage to the harness.

Section 5.5.1 Evaluation of Fixing Plugs by Clamping

This design squeezes the plug locking it in place. A representation of a clamp fixture is shown in Figure 6. The plug needs to be held in place by the operator until the clamp is closed onto the plugs. The difficulty of this would increase depending on the number of plugs being clamped. Consequently the time for plug fixture would greatly increase if the number of plugs increased. Alignment of each plug will not be exact. Alignment would need to be made by a separate device. This design was chosen to be compared to the other designs because of its simplicity and low cost.

Advantages:

- Simple to make and replace if needed.
- Fairly inexpensive to buy.
- Can be padded to protect cable plugs.
- Can apply more force to the cable plugs without damaging them.
- Easy to accept new plug shapes and sizes.
- May be adjustable to increase the number of plugs inserted.
- A small number of clamps are needed to fixing plugs.

Disadvantages:

- Will require more operator involvement.
- More prone to accidents.
- Takes a lot of time to fix the cable plugs.
- More difficult to position individual plugs in precise locations.

Considerations:

- Neoprene padding could be used to increase resistance to movement.

Section 5.5.2 Evaluation of Fixing Plugs by Clamping with Spacers

This design was chosen to be compared to the other designs because it is an improvement to the clamp design. Figure 7 shows a representation of the design. Plugs can be placed in the clamp with spacers with ease, and the spacers will hold the plug in place. Positioning plugs in exact locations is easily achieved with the spacers. Alignment should be checked but may not need to be made by a separate device.

Section 5.5.3 Evaluation of Fixing Plugs by Strapping with Spacers

This design was chosen to be compared to the other designs because it is an improvement to the clamp design. The strap material will be flexible, and fixing plugs with unusual shapes or fins can be achieved without damage to them. A representation can be seen in Figure 8. The spacers will help in aligning the plugs in exact positions. The force applied to plugs from the strap may affect the alignment. Alignment should be checked but may not need to be made by a separate device.

Section 5.5.4 Evaluation of Fixing Plugs by Clicking

The plugs will be individually inserted into a clicking device locking that plug in place. This process takes the least time to complete out of all the other designs. The plugs will be aligned with the most accuracy out of all the other designs. Thin padding can be added to minimize damage to the plugs. Springs added will determine the amount of force applied to the plugs. This design could include ejection of the cable after test completion decreasing operator involvement as well as overall testing time.

Advantages:

- Plugs can be rapidly inserted into the clamps decreasing positioning time.
- Plugs can be placed in precise locations.
- The clamp will make a clicking sound when a plug is placed properly.
- The plugs can be automatically ejected after testing.
- The operator will only need to handle one plug at a time decreasing complexity.

Disadvantages:

- The clicking device will were out faster than other devices.
- Some plugs may be scratched or marked when inserted.
- Cost. The clicking device will cost more to make.
- The clicking device is more complex. More work will go into creating and replacing the device.
- More difficult to adapt to new plug sizes and shapes.
- Requires more spacing between individual plugs from one cable.
- Several devices will need to be created to include in the cable harness tester.

Considerations:

- Springs can be added to increase the resistance to movement.

Section 5.5.5 Decision Matrix

By considering all advantages and disadvantages along with creating a decision matrix shown in Table 4 we concluded that the best design for fixing the cable harness plug was by clicking. With a total weighted score of 5560, the clicking device was the highest compared to the designs we evaluated. The reason for this is mainly due to the reliability, speed and ease of use that the device will have. The next highest weighted total score was 5495, the clamping with spacers design. This design score is comparable to the strapping with spacers design score of 5460, differing only by small increments. The clamping with spacers is less costly as well as slightly more reliable than the strapping design. This makes the clamping with spacers the second best design even though the flexibility of the strapping design is slightly better. The clamping design scored 5085 making it the least desirable design.

Table 4: Decision Matrix, harness plug fixture

		Clamping device		Clamping with Spacers		Strapping with Spacers		Clicking device	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Safety	100	6	600	6	600	6	600	7	700
Design Flexibility	95	8	760	8	760	9	855	4	380
Minimum Damage to Harness	90	10	900	10	900	10	900	8	720
Speed	85	3	255	5	425	5	425	9	765
Reliability	80	6	480	8	640	7	560	9	720
Life Expectancy	75	6	450	6	450	6	450	6	450
Ease of Use	75	2	150	5	375	5	375	9	675
Ease of Procurement	70	7	490	6	420	6	420	5	350
Ease of Assembly / Repair	55	8	440	7	385	7	385	6	330
Cost	50	7	350	6	300	5	250	4	200
Aesthetics	30	7	210	8	240	8	240	9	270
Total			5085		5495		5460		5560

Section 5.6 Evaluation of Controllers

The controller will be conducting the test for open conductors and crossed conductors. It must have input and output capability and be capable of storing programming for all part numbers. The controller is also responsible for all mechanical motion in the tester.

Section 5.6.1 Siemens Simatic S7-1200

Figure 13 shows a picture of the controller.

Advantages:

- Control the system with smartphone
- Ethernet and RS232/RS485 ports for communication
- Rugged compact enclosure
- Analog and digital expansion modules available in 8, 16, and 32 I/O channel configurations
- System can be adapted for the number of inputs and outputs necessary

Disadvantages:

- Parker Hannifin does not currently support this software.
- Cost is much higher than microcontrollers
- Less functionality compared to a microcontroller

Considerations:

- Parker could learn how to operate the new software

Section 5.6.2 Allen Bradley SLC 5/02

Figure 11 shows a picture of the controller.

Advantages:

- System provides a large degree of modularity allowing configuration of number of inputs and outputs as well as amount of memory and preferable communication networks.
- Designed to withstand vibrations, thermal extremes, and electrical noise concerns.
- High selection of network Ethernet, ControlNet, DeviceNet, DH+, and DH-485 networks
- Digital and analog inputs and outputs
- Analog and digital expansion modules available in 4-32 I/O channel configurations
- 4K-instruction memory
- Simple programming language with windows based software already in use by Parker Hannifin

Disadvantages:

- Cost is much higher than microcontrollers
- Less functionality compared to a microcontroller

Considerations:

- Configuration options available to control automation built into the tester design

Section 5.6.3 Allen Bradley MicroLogix 1000

Figure 12 shows the components of the controller.

Advantages:

- Compact Design
- RS-232 or EtherNet/IP communication networks
- Simple programming with windows based software already in use by Parker Hannifin
- Computer or Allen Bradley hand held controller are used for programming
- 65 Comprehensive Instruction Sets including bit, timer, high speed counter, sequencers, and shift registers.

Disadvantages:

- Device will only handle 20 inputs and 12 outputs.
- Cost is much higher than microcontrollers
- Less functionality compared to a microcontroller

Considerations:

- Can only test up to 12 conductor harnesses with no option for expansion. This leaves no option to control any automation in the design.

Section 5.6.4 PLC Decision Matrix

To determine the correct controller, several aspects must be considered to be able to choose the best fit unit for the system. The Allen Bradley SLC 5/02 programmable logic controller (PLC), with a score of 8910, was the most viable option that meets the needs of the design. Ease of use and programming along with Parkers familiarity of Allen Bradley PLCs is a major factor in the decision to use the SLC 5/02 to control the system.

Table 5: Decision Matrix, PLC

		SLC5/02		MicroLogix1000		Simatic S7-1200	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**	**Score**	**Weighted**
Safety	100	10	1000	10	1000	10	1000
Design Flexibility	95	10	950	2	190	10	950
Minimum Damage to Harness	90	10	900	10	900	10	900
Speed	85	10	850	10	850	10	850
Memory Capacity	85	10	850	2	170	10	850
Reliability	80	9	720	9	720	9	720
Life Expectancy	75	8	600	8	600	8	600
Ease of Use	75	8	600	8	600	4	300
Ease of Procurement	70	10	700	10	700	10	700
Change Overtime	65	10	650	10	650	10	650
Ease of Assembly / Repair	55	10	550	10	550	10	550
Cost	50	6	300	8	400	6	300
Aesthetics	30	8	240	6	180	8	240
Total			8910		7510		8610

Section 5.6.4 Microchip Microcontroller

Figure 14 shows a picture of the controller.

Advantages:

- Low upfront cost due to technological advances in components and manufacturing.
- 6 to 100 I/O pins
- 384B to 512 kB of program memory
- Up to 80 MHz processing speed
- 8, 16, and 32-bit families
- Can have Flash, OTP, or ROM
- Highly tested and industry proven

Disadvantages:

- High tail end cost since either someone on staff has to know the programming language, or an outside firm must program any updates
- Has function ability that is not needed for our application
- Schematic and PCB layout are not publically available

Considerations:

- Since the hardware and software are not open source, debugging problems and optimizing functionality may be difficult

Section 5.6.5 Raspberry Pi

Figure 15 shows a picture of the controller.

Advantages:

- Customizable since the programmer has full control of the code that is written
- Credit card size
- 256 Mb Ram
- 700 MHz CPU
- On board GPU
- Cost is only $25
- Supports Debian, Arch Linux ARM, Python, Perl, and BBC BASIC
- Schematic and PCB layout are publically available
- 2 USB ports which mice and keyboards can be interfaced
- Video output via RCA or HDMI
- Audio Output via 3.5 mm Jack
- 10/100 Ethernet (RJ45)
- Low Power 3.5 W

Disadvantages:

- No hard disk. Must use SD card for long term memory
- Programming must be done by a person trained in programming
- Does not support Windows or Mac
- Specification are set and not flexible
- Very new and therefore unproven product
- High tail end cost since either someone on staff has to know the programming language, or an outside firm must program any updates.

Considerations:

- Using the Raspberry pie could allow us to have a very easy to follow intuitive interface

Section 5.6.6 Arduino Microcontroller

Figure 16 shows a picture of the controller.

Advantages:

- Supports Windows, Mac, and Linux
- Open source hardware and open source software
- Specification are very flexible to the user's needs
- Digital I/O pins range from 14 to 54
- USB interface
- Can have Flash, EEPROM, and/or SRAM
- Less expensive than Microchip Microcontrollers

Disadvantages:

- Programming must be done by a person trained in programming.
- Programming must be done in C/C++
- More expensive then Raspberry Pi
- Not widely accepted for commercial use
- High tail end cost since either someone on staff has to know the programming language, or an outside firm must program any updates.

Considerations:

- Since the hardware and software is open source, the programming will be made easier

Section 5.6.7 Non PLC Decision Matrix

A decision matrix was constructed for all three of the choices. The Microchip microcontroller yielded the highest weighted score of 8520. The Raspberry Pi scored 8000, which is lower than the Microchip mainly due to procurement, reliability, and life expectancy concerns. The Arduino scored 7145, which is lower than the Microchip mainly due to reliability and life expectancy concerns along with the inability to meet all requirements.

Table 6: Decision Matrix, PLC alternatives

		Microchip		Raspberry Pi		Arduino	
Criteria	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**	**Score**	**Weighted**
Safety	100	10	1000	10	1000	10	1000
Design Flexibility	95	10	950	10	950	2	190
Minimum Damage to Harness	90	10	900	10	900	10	900
Speed	85	7	595	10	850	6	510
Memory Capacity	85	10	850	10	850	10	850
Reliability	80	8	640	6	480	6	480
Life Expectancy	75	8	600	6	450	6	450
Ease of Use	75	5	375	6	450	7	525
Ease of Procurement	70	10	700	3	210	5	350
Change Overtime	65	10	650	10	650	10	650
Ease of Assembly / Repair	55	10	550	10	550	10	550
Cost	50	10	500	9	450	9	450
Aesthetics	30	7	210	7	210	8	240
Total			8520		8000		7145

Section 5.7 Selected Designs

It should be noted that the design selection has been done in a modular way. This is because the aspects of the group's design are independent of each other and any combination of concepts from each module could be implemented. So our "selected design" is a combination of the concepts with the highest scores in their respective decision matrices. The backup design contains all of the concepts which came in second in the decision matrices. If a particular concept in a module of the overall design fails, the backup option for that module will be substituted, rather than replacing the whole of the "selected design" with the whole of the backup design. Shown below in Table 7 are the primary and secondary design choices.

Table 7: Primary and secondary design choices

Primary		Secondary	
Control System	Allen Bradley SLC5/02	**Control System**	Microchip Microprocessor
Pins	Spring Loaded Pins	**Pins**	Rigid Pins
Pin Configuration	Fixed without Cards	**Pin Configuration**	Fixed with Card
Pin Array Motion	Linear Actuation	**Pin Array Motion**	Rack and Pinion or Servo with Arm
Harness Plug Fixture	Clicking Device	**Harness Plug Fixture**	Clamping with Spacers

Section 6: Detailed Design

Section 6.1 Detailed Design of the Selected Final Concept

The electrical cable tester designed will be a unit that stands on the production floor in the Parker facility in New Haven, Indiana. The frame will be made from Parker's Industrial Profile Systems extruded aluminum products, while most of the moving parts will be made from machined aluminum, steel, and stainless steel. The user will stand in front of the machine to operate it. The interface selected for operation will be a Parker CTC touch screen, with simple start and stop controls. A rendering of the tester is shown in Figure 17.

Figure 17: Electrical Cable Tester

The mechanically working parts are all mounted to a single assembly, which incorporates a linear actuator. This assembly will be mounted to the frame with bolts and t-nuts. A rendering of the mechanical working parts is shown in Figure 18. There are several places for the user to click the plugs into place, with a few plugs shown in position. The pins shown will be spring-loaded and aligned with the terminals in the plugs.

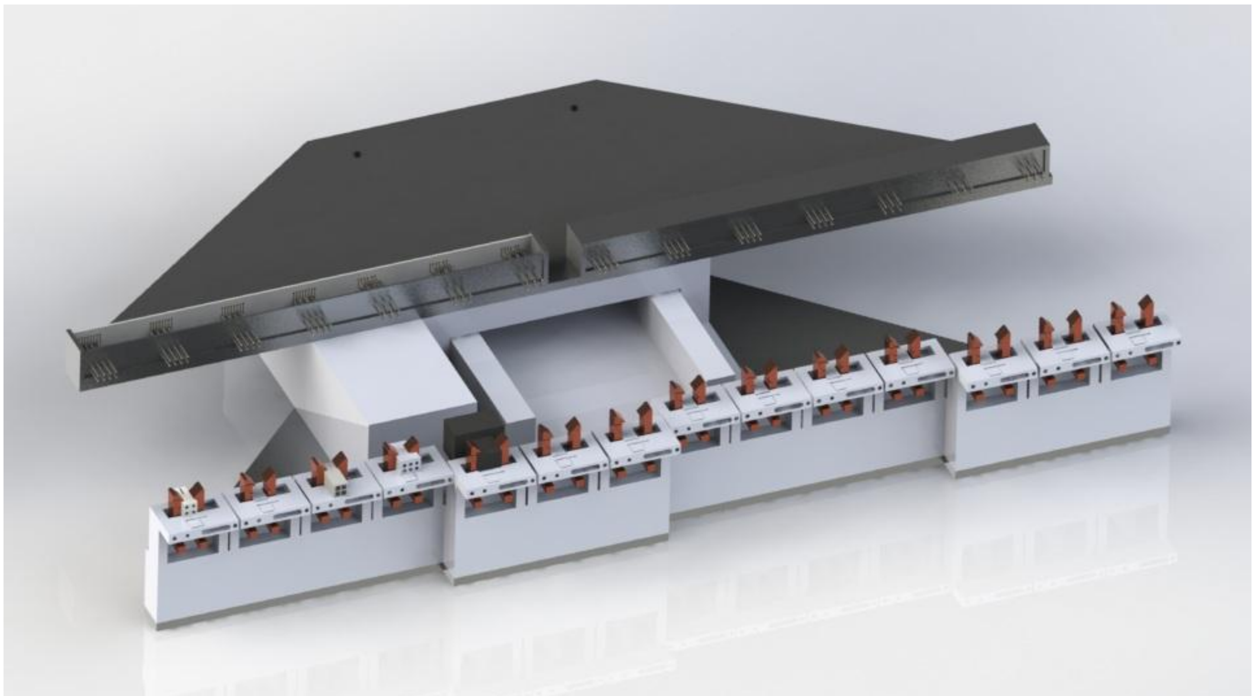

Figure 18: Moving Parts in the Electrical Cable Tester

Section 6.2 Spring-Loaded Pins

It was determined that a max stroke length of 0.480" was desirable for the application; this determination will be discussed later in this document. In order to meet the guideline of 0.480" stroke length and to fit easily into 0.090" square holes in the smallest plug, a pin design incorporating fairly large length to diameter ratios was created. The final pin design is depicted in Figure 19. As shown, it is 0.050" in diameter at the point of connection, and 1.45" in length. The pins are to be made of stainless steel for its properties of strength, electrical conductivity, and corrosion resistance.

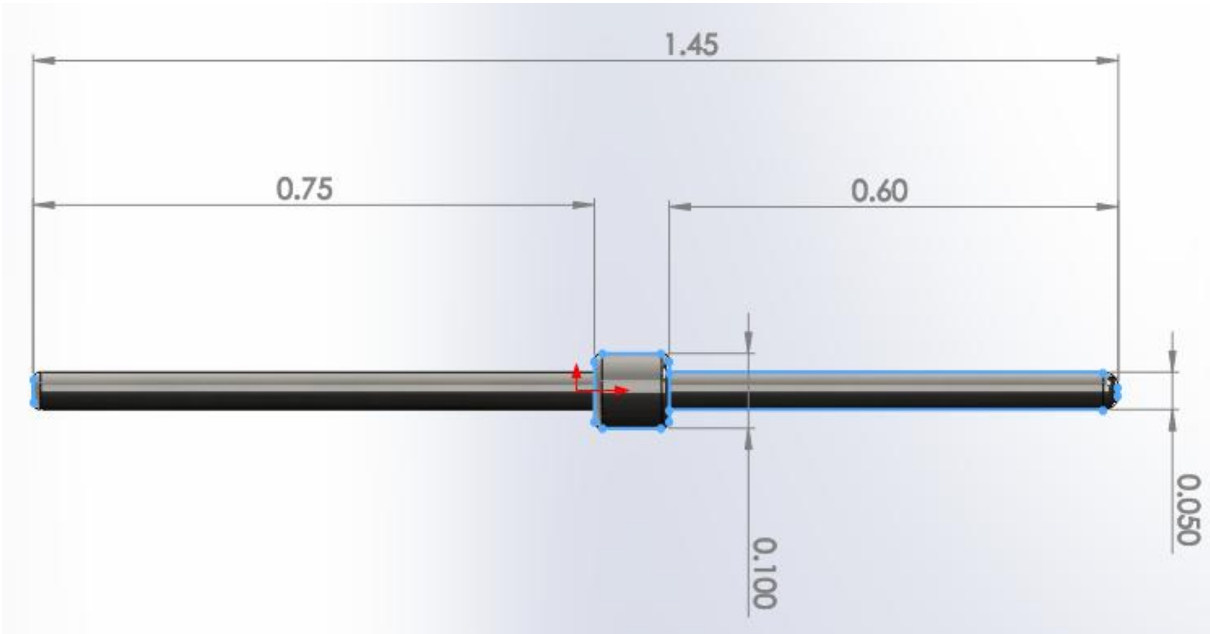

Figure 19: Pin Dimensions for Spring-Loaded Design

The spring for the spring-loaded pin has been selected based on a minimum terminal retention force of about 20 lbf, found on test summary documents obtained from Tyco and Molex. With a max stroke length of 0.480", the spring constant must be below 41.7 lbf/in to avoid pulling the terminals out of the plug housing. The spring selected has a spring constant of 1.27lbf/in, giving the terminal retention force a safety factor of 32.

Section 6.3 Fixed Pin Array

In order to keep the pins aligned with the plugs, the spring-loaded pins will be arranged in a fixed configuration inside a rectangular box. The front and back of the box will incorporate holes which the pins will ride in. These holes will serve to space the pins appropriately and guide the shaft of the pins to their intended points of contact. The box can be seen in Figure 20, with the top panel removed to expose the springs inside.

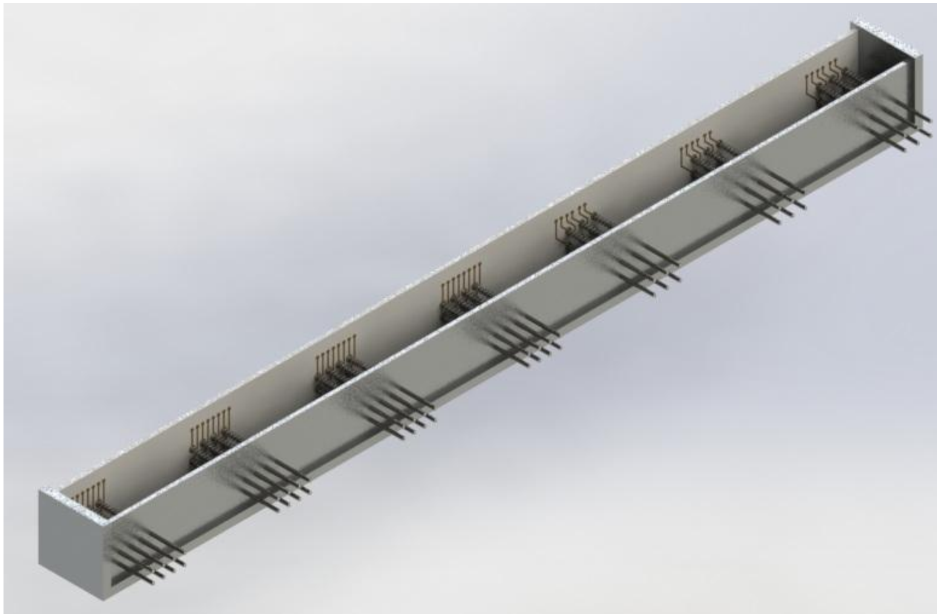

Figure 20: Rectangular Box Containing Spring-Loaded Pins

One configuration of the pins was decided to be in grids of four pins by two pins, at a spacing of 0.164". All plugs used by Parker have only two rows of pins, which is why two rows were used for all pin configurations. The pins at this spacing line up well with the connectors in most of the plugs. For the plugs with different pin spacing, a separate part of the grid must be used, which has a pin spacing of 0.200". For this section, the all plugs tested will be two connectors by three connectors, so six pins were used in this configuration. The pin configurations are depicted in Figure 21.

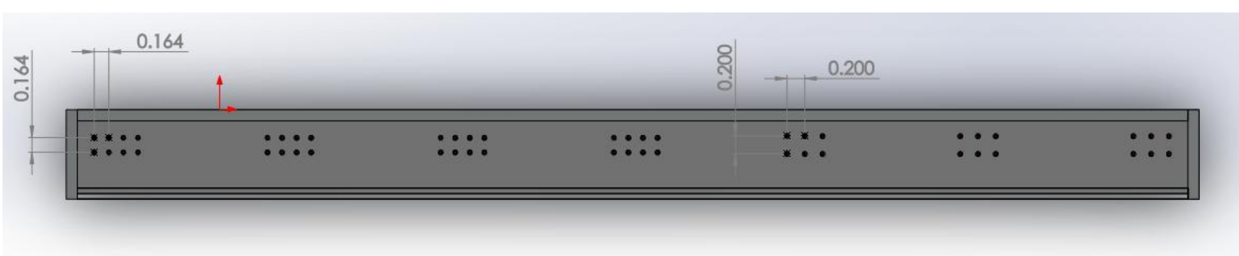

Figure 21: Pin Configuration

Section 6.4 Pin Array Motion

Linear motion is achieved by utilizing a Parker linear table. The stage provides an accurate motion with the use of a Parker stepper motor and lead screw. The stage has overall dimensions of 4 x 4 x 16 (in). It has a load capacity of 375 (lbs). This stage was chosen for its thrust capacity of 200 (lbf) and travel of 4 (in). Since the plugs are not lined up some springs will have more force than others. Our harness that will require the most force has three connectors on each side. On one side the springs will be compressed 0.2 (in) and the other side will be compressed 0.4 (in). Each plug has three conductors. The resulting force the stage needs to apply is 6.858 (lbf). The following image, Figure 26, is of a similar ultra-series stage.

Figure 26: Image of a Parker 406XR Linear Table

Section 6.5 Plug Fixture

The clicking device shown in Figure 27 is designed to minimize damage to the plug as well as ease of use and flexibility. The clamping arm has been designed to have rounded corners at locations that the arm will come into contact with the plug. This is to remove any chance of scratching or damaging the plugs. The 45° angles at the top of the clicking arms are to allow the plugs to be pushed into the locked position. This makes fixing the plugs in desired locations quickly and easily possible. The clicking assembly has 4 parts. Two parts are the right and left clicking arms. These arms are slightly different from one another. The right arm is designed to move in the horizontal plain only. This is to make the device have the capability of testing plugs of many different lengths adding flexibility to the design. This arm will be fastened in place during initial setup. Once fastened in place the clicking mechanism will be able to test the same plug repeatedly with no further adjustments. The left arm can only rotate about a fixed point. This allows a plug to be inserted into the center of the two arms. The spring shown in Figure

28 will give the left arm a torsional force to fix the plug once inserted. The body of the assembly is separated into two halves, front and back. The back half is what connects the clicking mechanism to the rest of the cable tester device. Both front and back combined hold the clicking arms in place. The front part is connected to the back half by screws. The top face of the front part is scored with various shapes. These shapes are designed to add flexibility and support. These mechanisms will be made from steel and either fabricated in Parker's facility or at one of the machine shops they frequently order parts from.

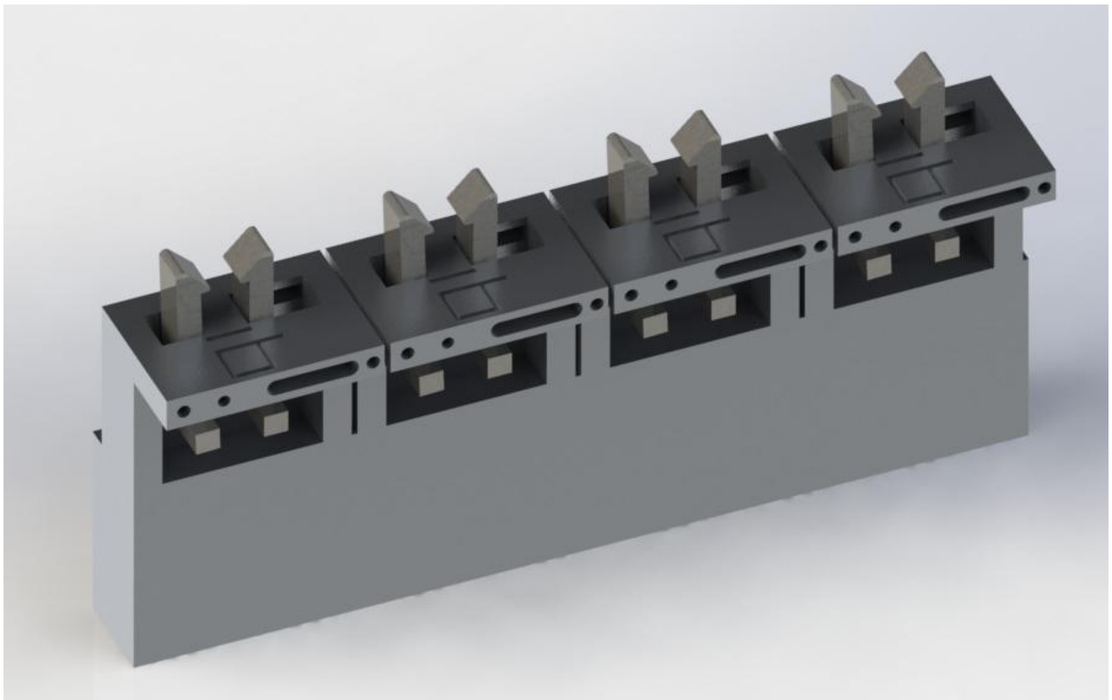

Figure 27: Plug fixture assembly

During testing, the plugs must be fastened in place so that the forces of the spring-loaded pins do not move them and so that the pins can make contact with the terminals consistently. As previously discussed, the differing geometry of each plug posed several challenges. The first of these geometrical challenges is visually represented in Figure 29. It can be seen that the geometry of each plug is unique. The locations of the flat side surfaces on which the tooling can locate for orientation and locations are in different locations in each plug, shown in orange. In order to orient the flat surface on the side of each plug, clips, contours, and additional steps will be required. The team has visually analyzed the geometry of each plug to find similarities between all plug shapes. It has been found that all plugs have a flat bottom surface that can be located from, and a perpendicular vertical surface which can be located on. Each plug also has a unique geometry protruding from the lower edge, which will cause the plug to not sit flat if not accounted for.

The clicking mechanism is designed in such a way to easily remove the plug when the testing is complete. The applied force from the operator required to open the clamp arm is set at a max of one pound, which is a comfortable weight for an average operator. The reason for a one pound force requirement is to make the process of removing the plug easily repeatable for the operator. The plugs are made from a hard plastic material (Nylon 6/6) that has compressive strength of 300psi at 2% deformation. Deformation of the plug under a compression force of one pound will never occur. This will meet our design requirement of no damage to the plugs. The clamping arm will be rigidly attached to a torsional spring to achieve this one pound clamping force. The spring will need to fit over a 0.11 inch diameter rod. Springs that have the properties that will fulfill the design requirements specified are available for purchase at McMaster-Carr. This torsion spring, shown in Figure 28, has the specifications as follows: torque of 0.402 in-lbs. at a 90o angle rotation, 0.235 inch outer diameter, o.140 inch max rod outer diameter, 0.750 inch leg length, 3.25 coils, and a 0.096 inch spring length at 90o torque. This spring will translate a maximum of 0.402 pounds to the end of the clicking arm at full rotation, and will be loaded at a rotation of 45o which translates 0.201 pounds to the plug when clamped.

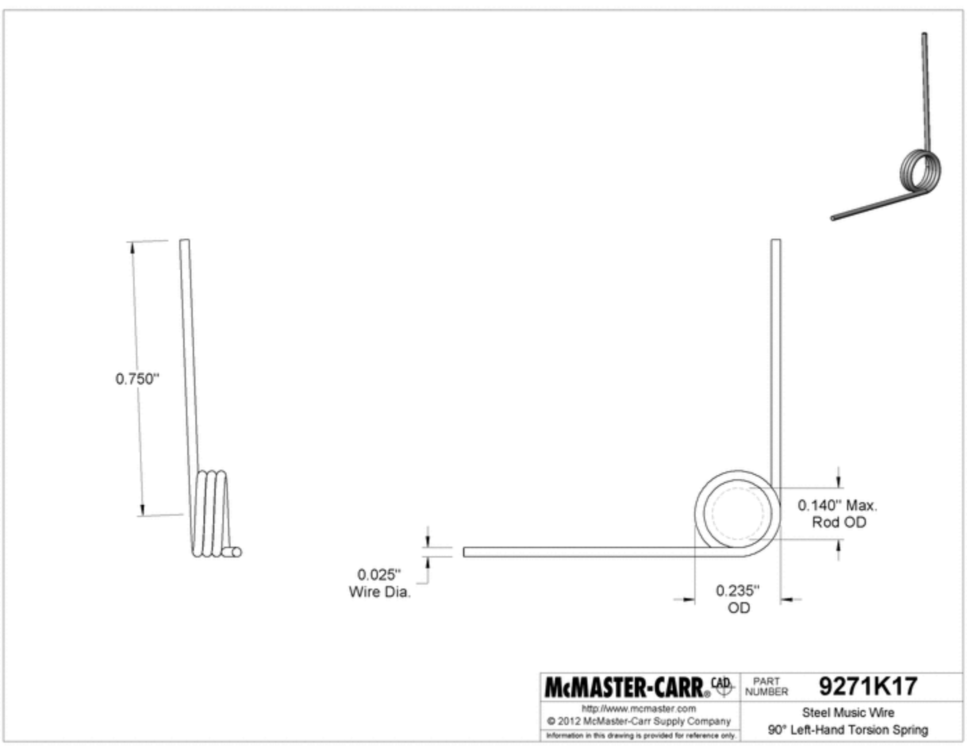

Figure 28: Torsional Spring used for Plug Fixture.

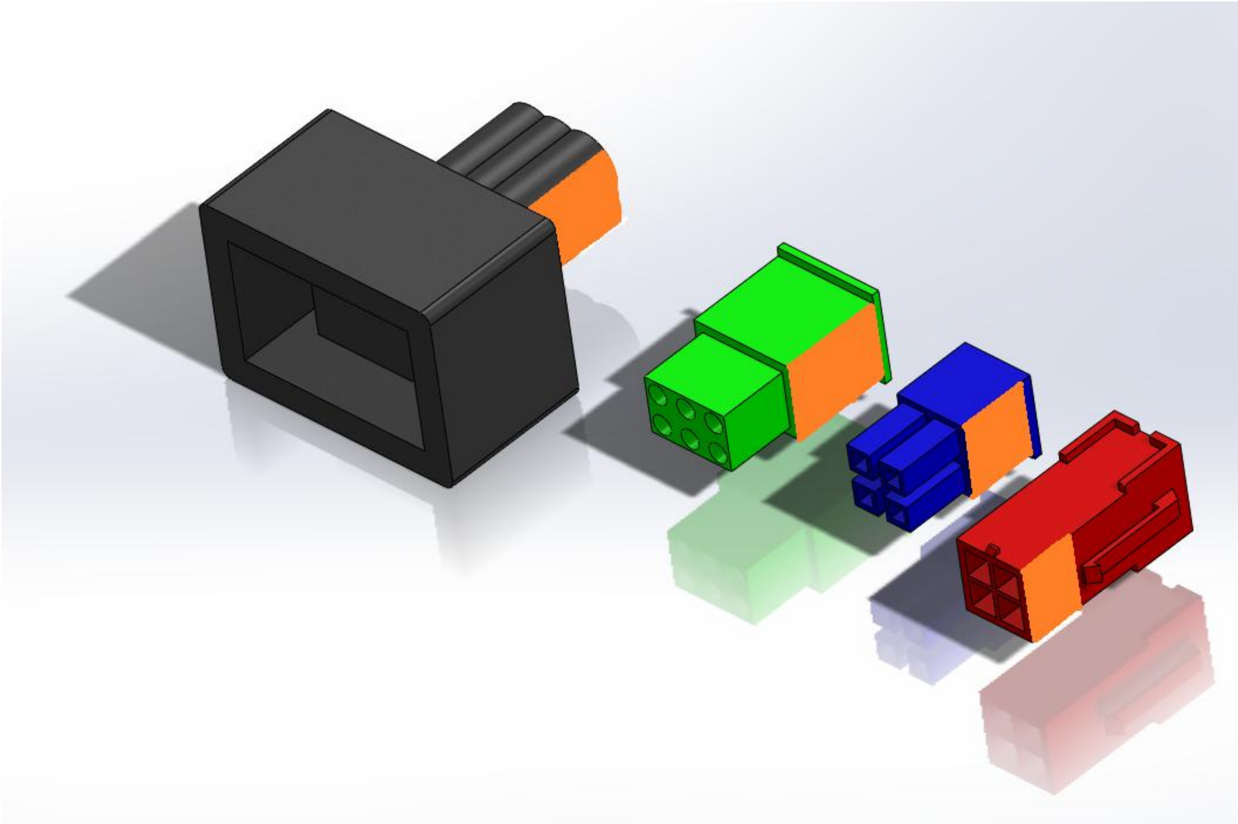

Figure 29: Illustration of Vertical Faces Available for Tooling Location

Clips on the surfaces must be avoided with tooling, and unique geometry on the bottom surfaces of the plugs have been integrated into the base plate of the universal click-in plug holder. In Figure44 the design of the universal plug holder can be seen with each plug sitting flush on its surface. The various lengths of the plugs cause their faces to be in different positions, illustrating the need for relatively long travel of the spring-loaded pins. As seen, max dimensions of pin travel should be 0.460", but 0.020" was added for dimensional tolerance stack-ups in machining. This leaves a max travel of 0.480" for the spring-loaded pins.

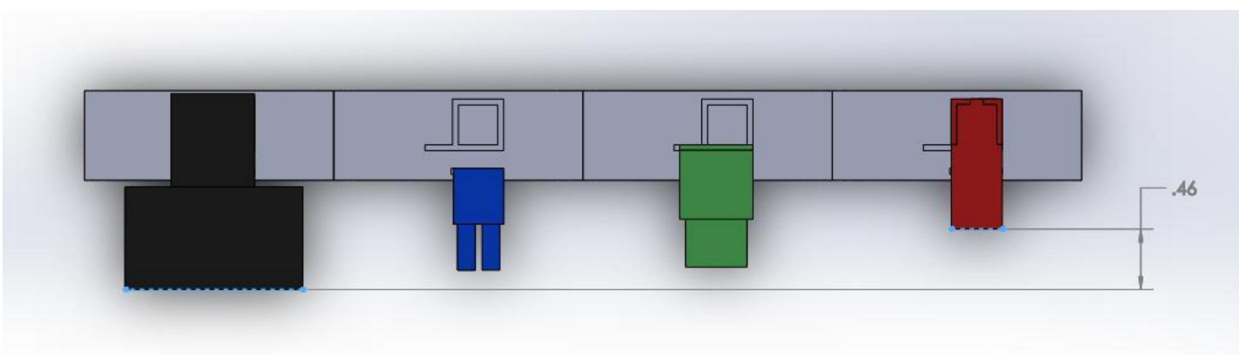

Figure 30: Alignment of Plug Faces When Fixed in Tooling

Section 6.6 Analysis

Section 6.6.1 Pin Array Analysis

In The circuit board will have an aluminum backing plate to dissipate the load applied by the test pin return springs. This plate is constructed out of 6061 (T4) Aluminum that is 0.125 (in) thick. The return springs chosen have a spring constant of 1.27 (lbf/in). When the pins are in their resting position the spring will be compressed 0.087 (in) resulting in a force of 0.11 (lbf) at the base of each spring. The following image, Figure 22, is of the FEA model created in SolidWorks for the resting load on the aluminum backing plate.

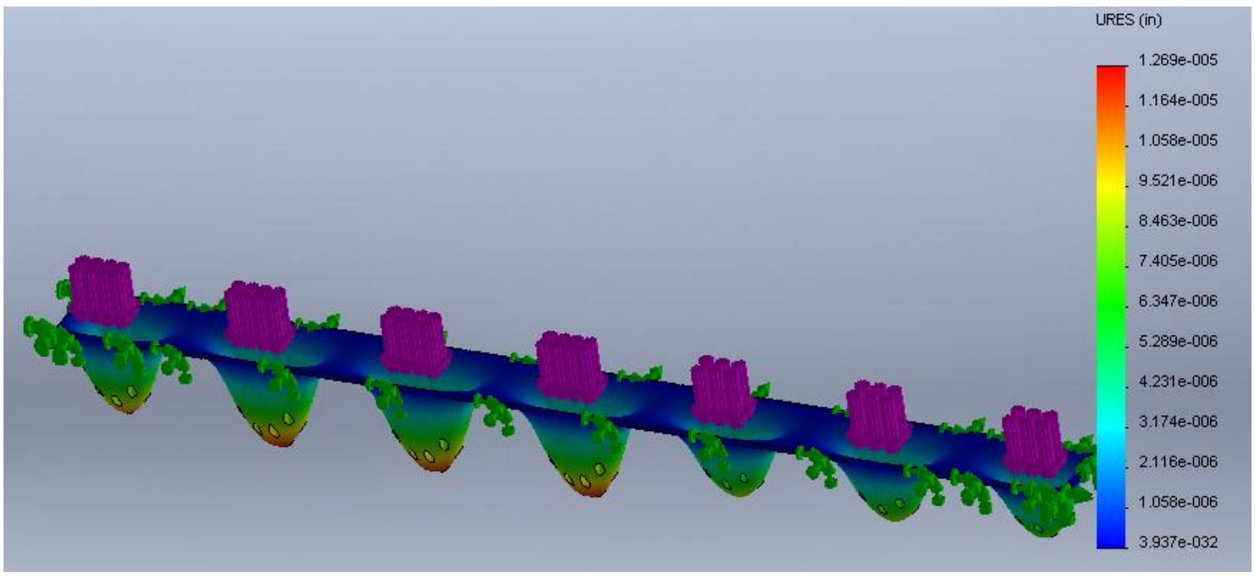

Figure 22: FEA on the deflection of backing plate (min force)

The maximum deflection occurs at the center of the pin clusters. The scale reports the maximum deflection of about 0.00001 inches. The pins have sufficient travel when being compressed so this deflection will not cause any problems.

The maximum spring deflection can be seen in the Figure 23 which is 0.46 (in). At this deflection each spring will exert a force of 0.7 (lbs) at the base of the spring. Figure 24 is the SolidWorks FEA analysis of the spring backing plate with the force mentioned. The springs will be purchased from www.LeeSprings.com

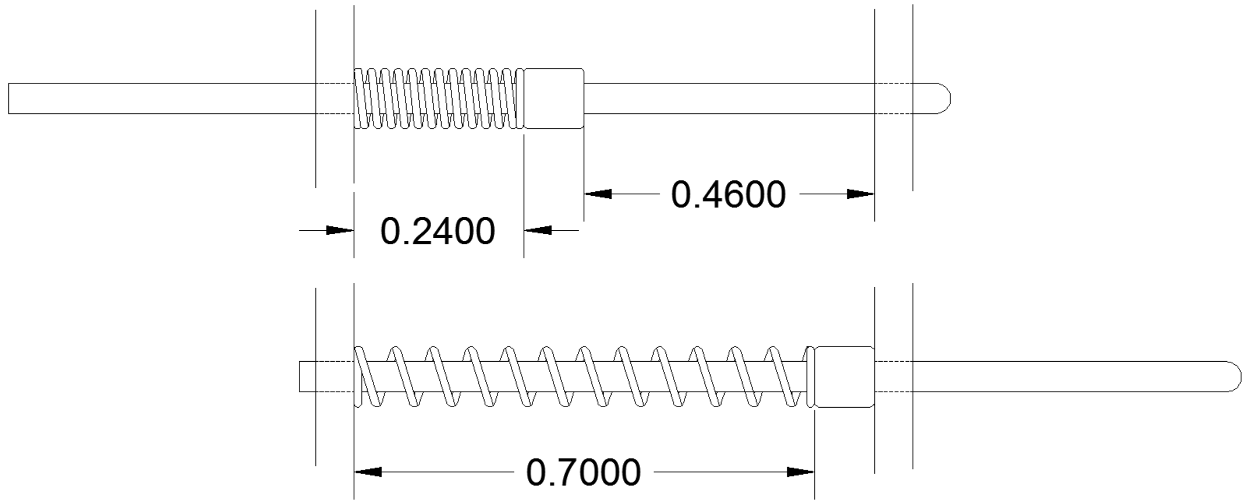

Figure 23: Minimum and maximum compression of extension spring

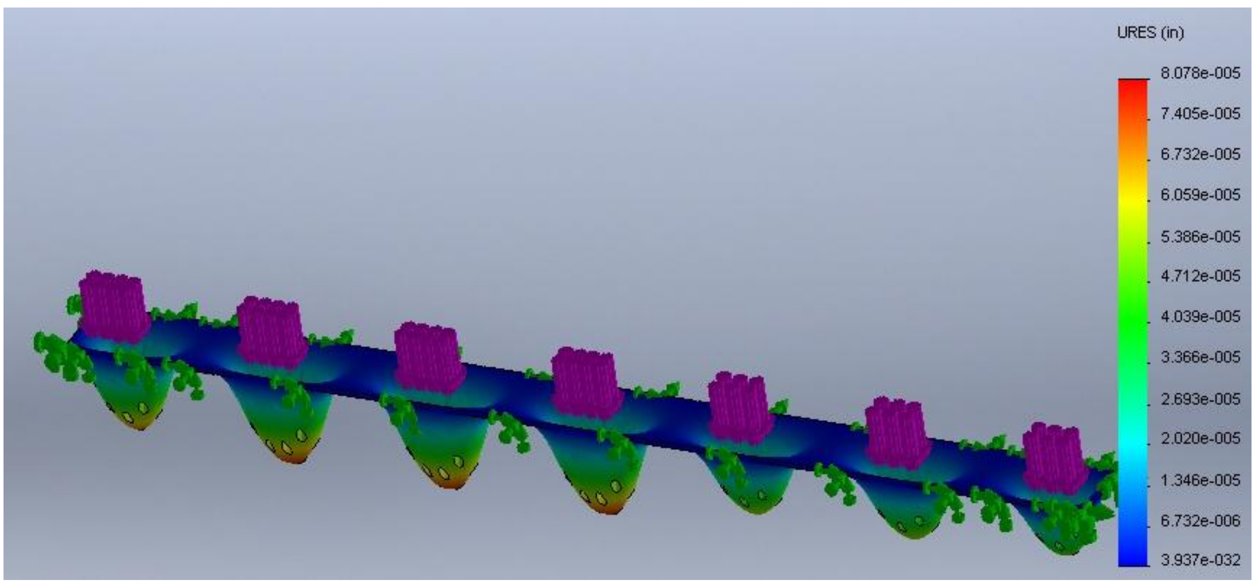

Figure: 24 FEA on the deflection of backing plate (max force)

Again the maximum deflection occurs at the center of the pin clusters. The scale reports the maximum deflection of about 0.00008 inches. We do not expect this deflection to cause any unwanted conditions. We expect the machining process performed on the pin to have a best case accuracy of 0.0005. The deflection is less than the expected machining tolerance. With the same reasoning we do not expect any problems when the springs are in there resting position.

Section 6.6.2 Pin Array Support Analysis

The pin assembly and supporting plate both sit directly on top of the linear actuator. The linear actuator has an advertised weight limit of 1900 (lbs). The total weight of the components that will be on top of the actuator is 2.2 lbs. Our design is far less than the maximum load rated for the linear slide. FEA analysis was performed, using SolidWorks, on the structure that sits on top of the linear actuator. The linear slide has a very small platform and the pin housing has a very long thin construction. FEA was performed to ensure the ends would not droop and cause miss alignment with the pins and the tested harnesses. Figure 25 is of the FEA model.

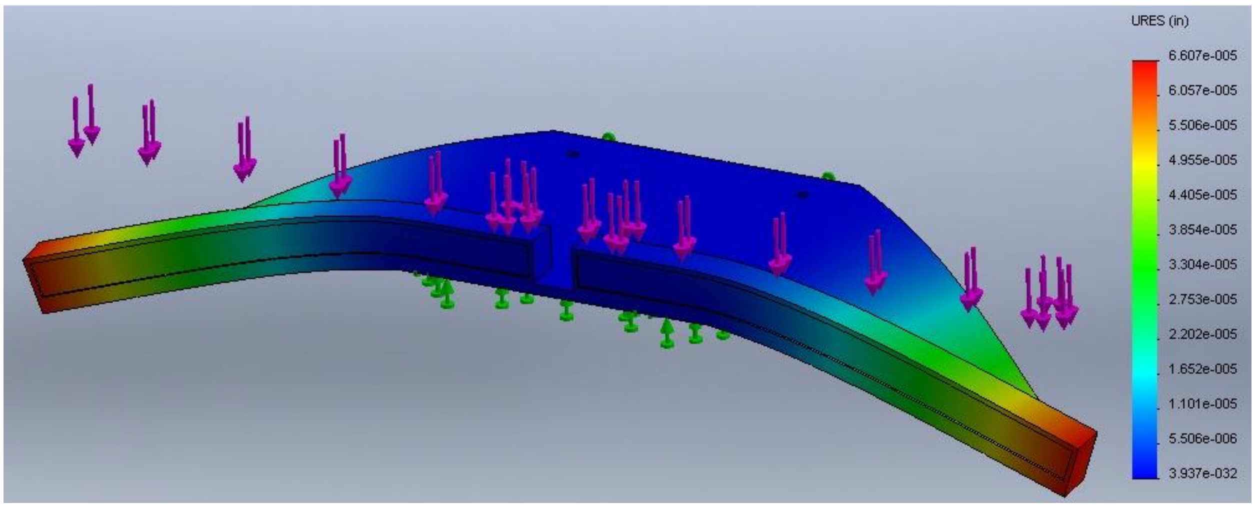

Figure 25: FEA on deflection of the pin housing

It can be seen that the maximum droop caused by gravity is about 0.00006 inches. The diameter of a pin is 0.05 (in). The amount of deflection caused by gravity is not enough to cause miss alignment of the pins and cable harness. The smallest opening in any of the plugs is 0.09(in). That gives a difference of 0.04. Half of that is the tolerance before the pin contacts the plug and is 0.02 (in). The deflection is far less than the allowable movement.

Section 6.7 PLC Controller

The final controller selection is an upgraded version of the Allen Bradley SLC500 system that was chosen previously. It was found that the SLC500 system will eventually be phased out and replaced with the Allen Bradley CompactLogix logic system that uses upgraded software, RSLogix5000. The base of the system will be the 1769-L35E CPU. This processor utilizes 1-RS232 and 1-Ethernet/IP port for communications. The RS232 port will be used to connect to the user interface for the tester and the Ethernet port will be used for programming. The system also requires a way to power the I/O modules. To do this a 1769-PA4 power supply was selected which allows up to 8 modules, 4 on each side, to be added to the system without adding another supply. For communication with external sensing devices a 1769-SDN DeviceNet network module will need to be added. This module provides connections between simple industrial devices such as sensors and actuators and higher-level devices such as PLC controllers and computers.

For the testing of the cable harnesses the CompactLogix system will be incorporated with two 1769-IQ16 16 input 24V DC sinking or sourcing modules as well as two 1769-OB16 16 output 24V DC sourcing modules. These modules will give the system the capability to send a signal from one end of the harness and read it from the other to verify correct configuration of the unit under test (UUT). To achieve the 24V output a Weidmueller 24 Volt, 10 amp DC power supply is selected. Using an external power supply will separate the main controller power system from the power system used for testing purposes.

The system also will need a method for the user to interface with the system. For this a PC based Human-Machine Interface (HMI) CTC 6" touch screen panel will be utilized. This interface will give the user the ability to start and stop the test and change part numbers. The interface panel will be mounted on an enclosure along with an emergency stop button and a system enable button. This can be seen below in Figure 31.

To complete the system the components will be installed into a steel Hoffman enclosure with the layout shown in Figure 32. This will bring the components together into one enclosure and allow for easy mounting onto the electrical cable tester frame. Shown in Figure 31 are the PLC components, the power supply, and terminal blocks. Fusing, power entry and safety relays are shown in the box as well. Values were selected but may change. More time is needed to verify the correct ratings for these components. This will be completed for the final design.

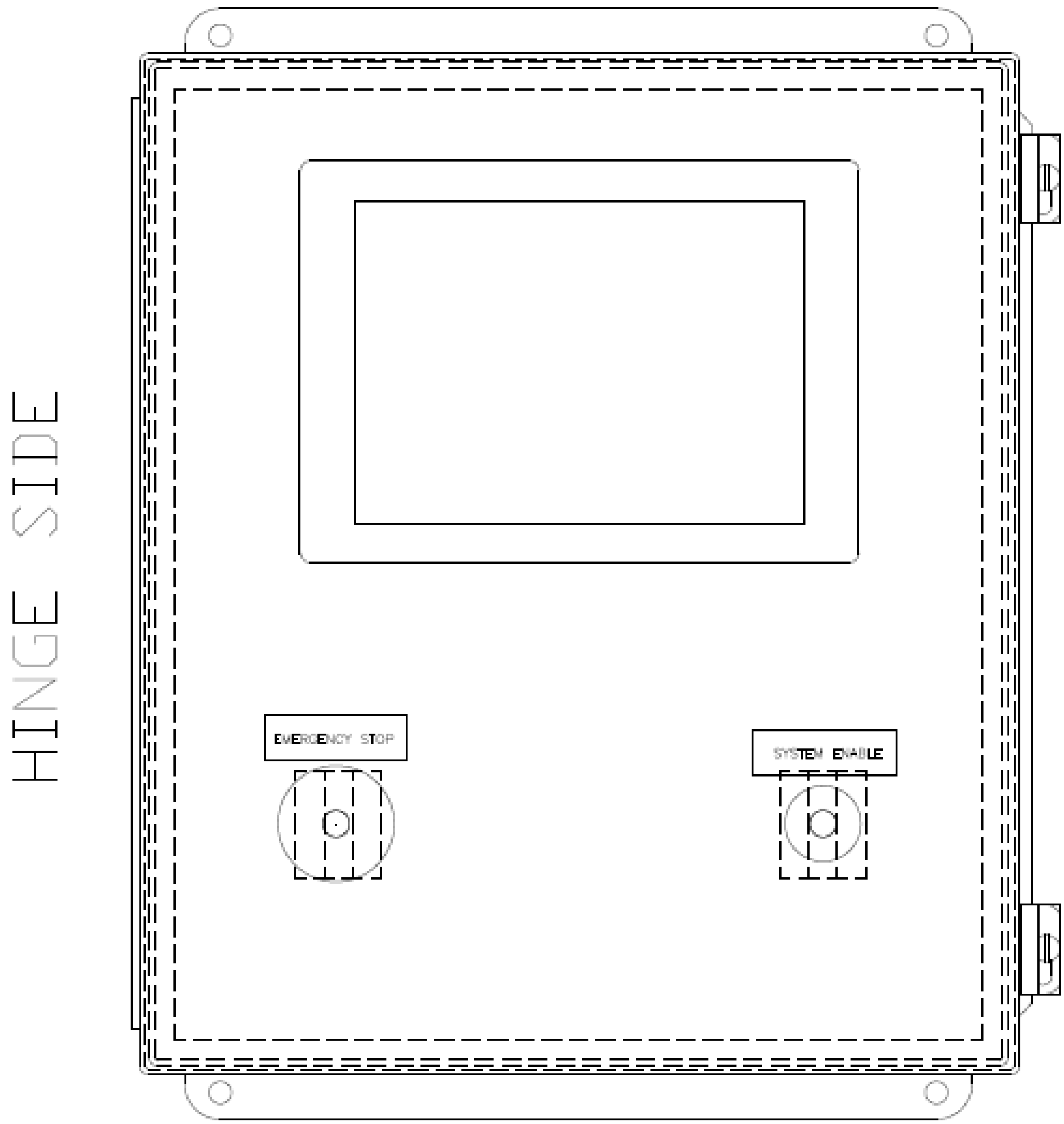

Figure 31: Operator Box Enclosure

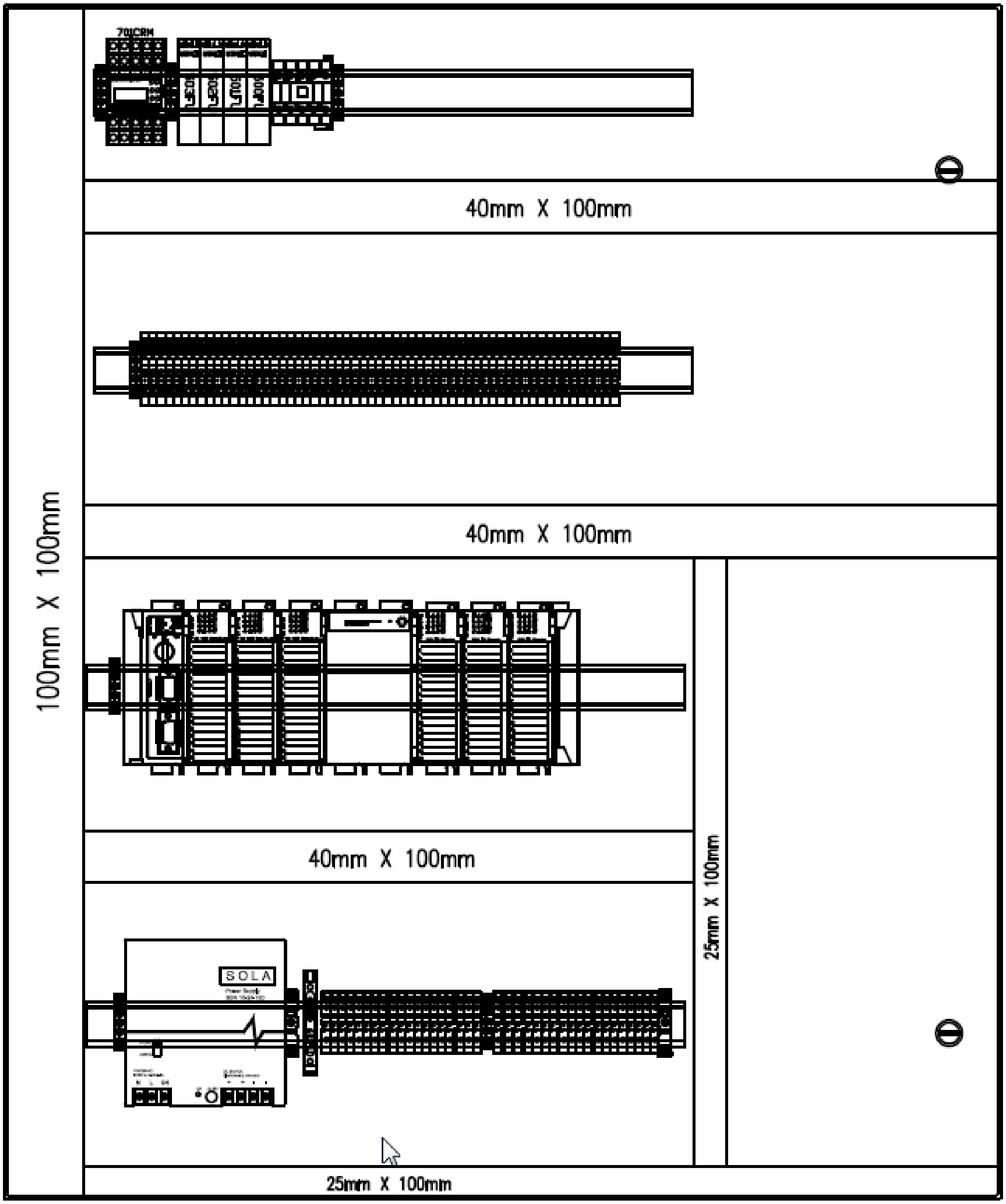

Figure 32: Operator Box Enclosure

Figure 33, shown below, shows the AC distribution within the box. The PLC, the power supply and the safety relay are all powered by 110 VAC.

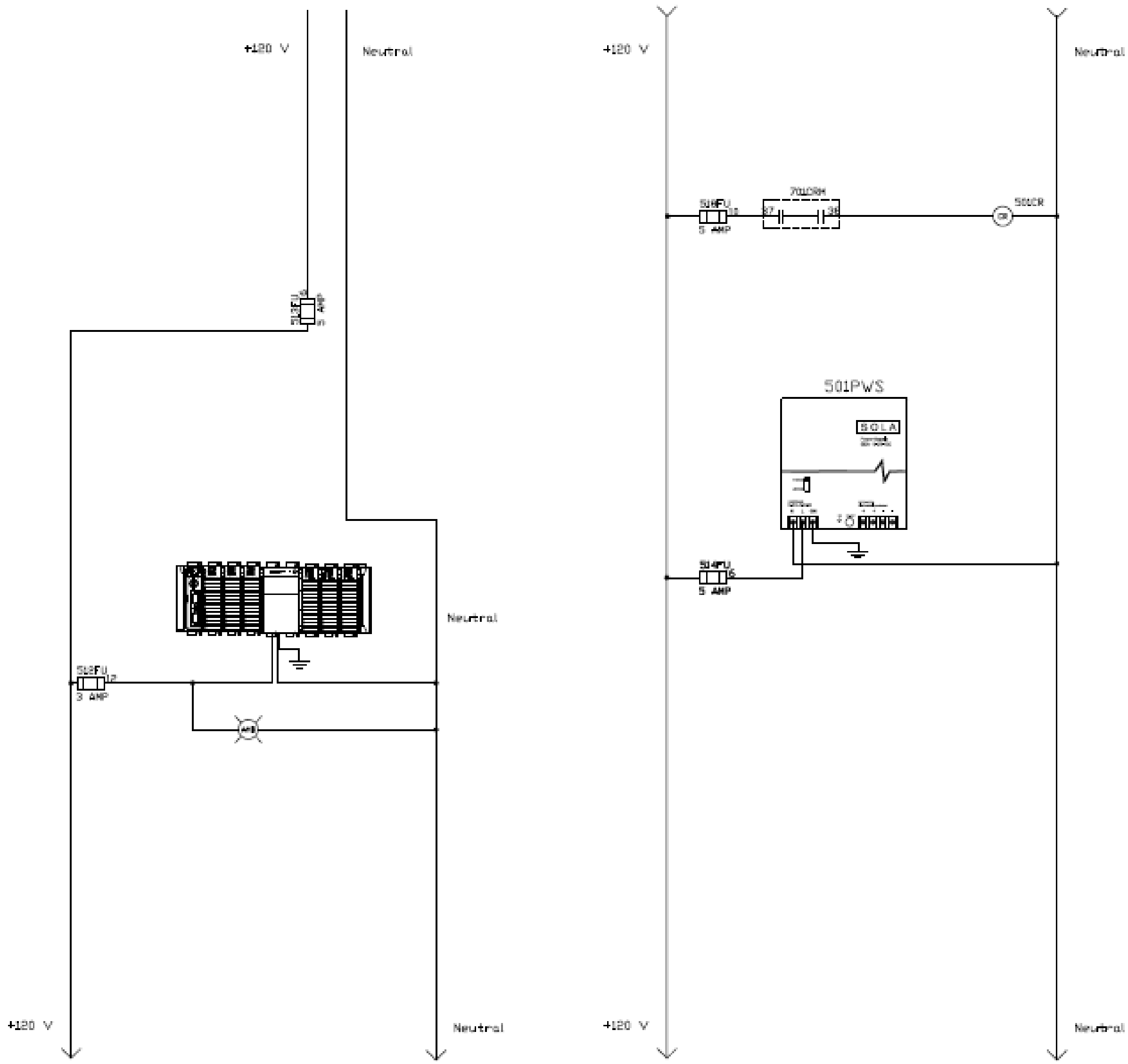

Figure 33: AC Circuit Distribution

Figure 34 shows the DC distribution. The power supply powers the linear motor for pin array movement, the touch screen and the PLC input and output modules.

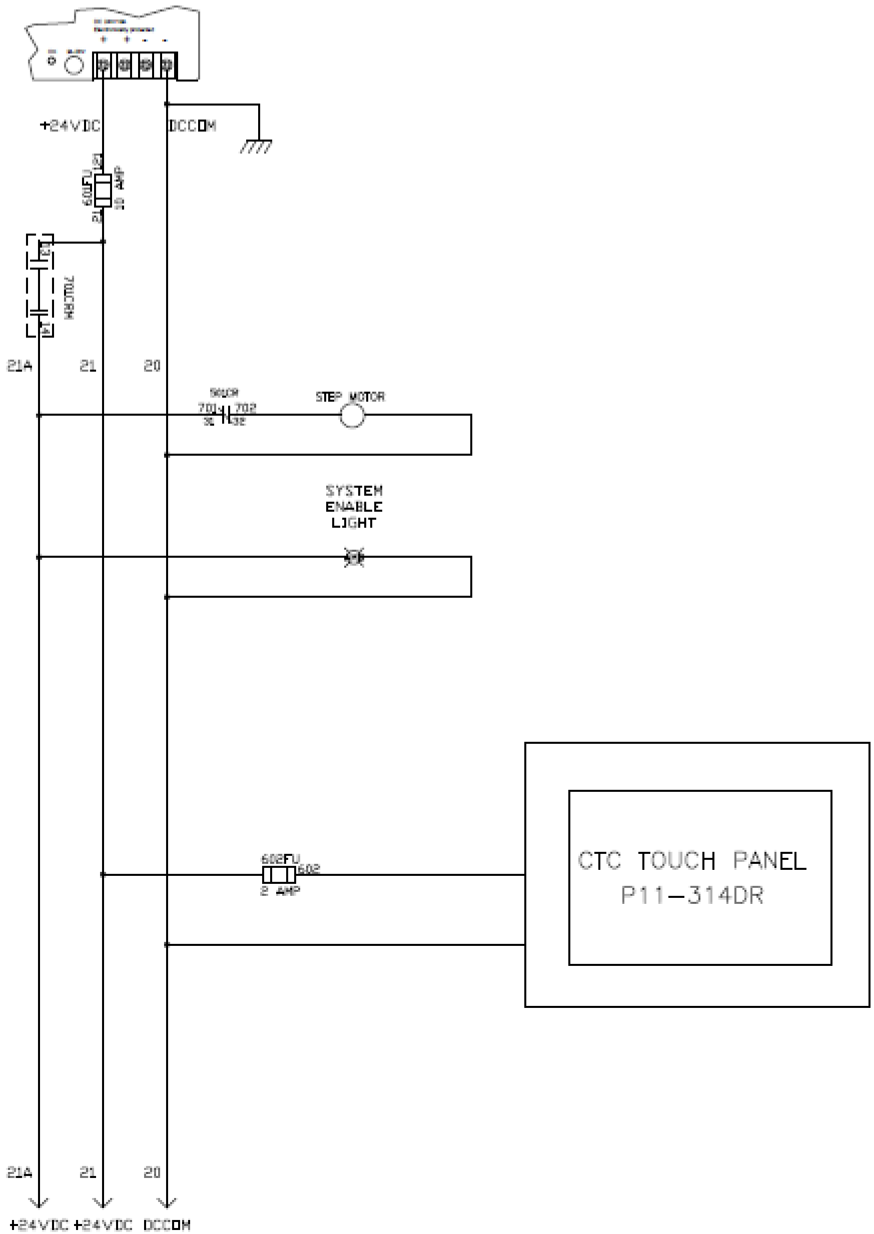

Figure 34: DC Circuit Distribution

Section 6.7.1 Test Program

The cable harness tester will be controlled by software loaded on the Allen Bradley PLC. Software written for PLCs is often in ladder logic format. Each rung in the ladder is completed from left to right and the rungs are completed from top to bottom. Operations on the rungs can change stored values, accept inputs, or send outputs. Some PLCs, like the Allen Bradley CompactLogix being used, also have many functions that can perform more complex tasks, such as mathematics, timed inputs/output, or looping. The main functions our ladder logic program will incorporate include timed inputs and outputs and register value shifting.

The basic flow of the program to be created for the cable tester can be seen in Figure 35. The program will be initiated by the operator of the tester after the harness to be tester has been fixed. The program will apply a 24V DC signal to the first designated conductor on the side of the harness designated input side. Output conductors of the harness will then be progressively scanned by the program to locate which conductor, if any, has the 24V potential. The conductor number(s) that sense the potential will be stored until the end of the program. This cycle is repeated for each input conductor.

When the program has finished scanning all the input output combinations, the operator will see an output on the tester monitor. Correct harnesses output will display the word "Pass" with a green background to reinforce that the harness connections are electrically correct. Incorrect harnesses will display the word "Fail" with a red background to reinforce that the harness is not electrically correct. The operator is then given the option to display the data collected by the program about each input conductor. This diagnosis will be optional to accommodate for timely testing and involved diagnosis needs. Before the operator can test the next harness, a reset button must be pressed. This will ensure that the operator has seen the output screen which reduces the chance of placing a "Fail" harness in the "Pass" harness location.

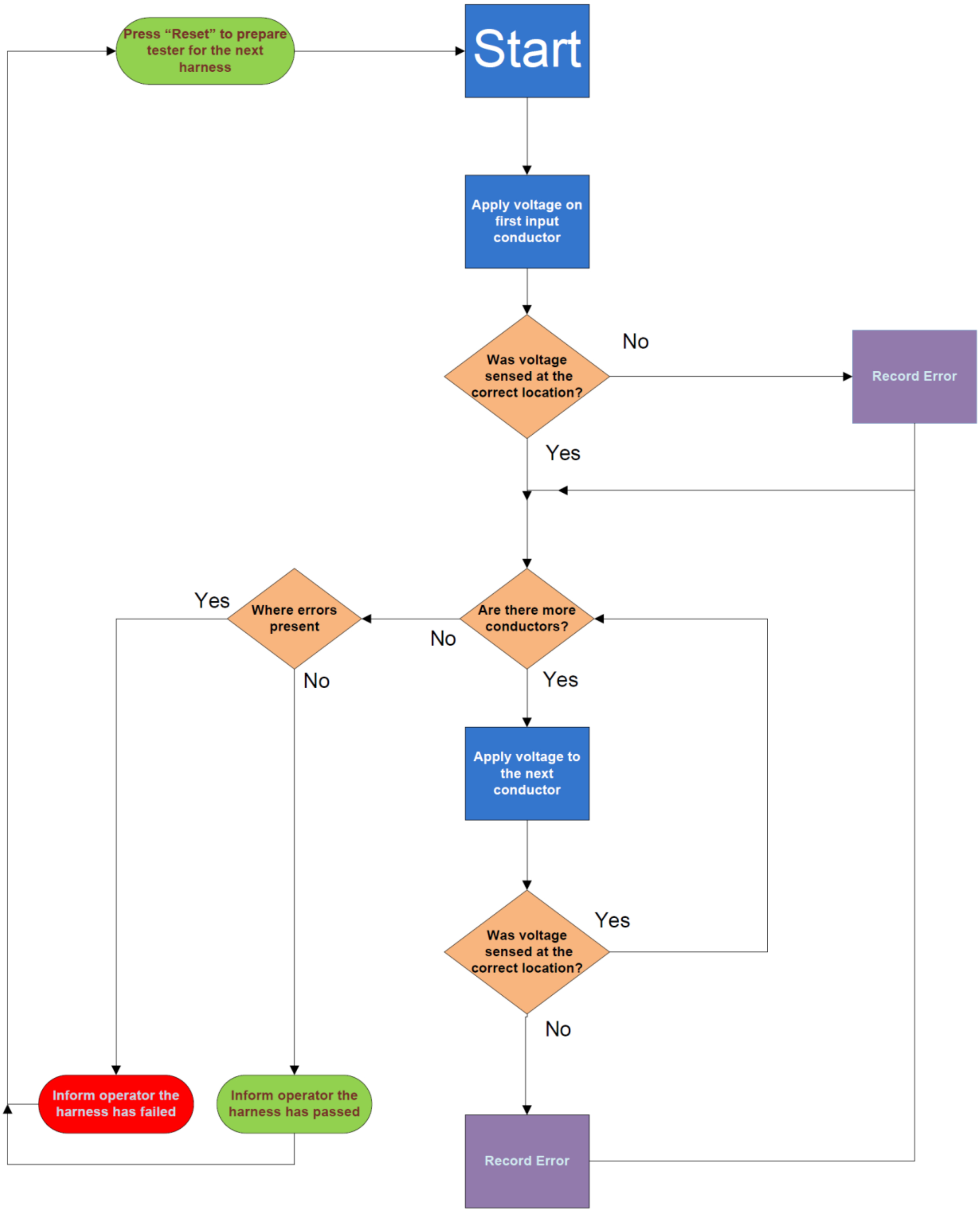

Figure 35: Flow Chart of PLC Program

Section 7: Cost Analysis

Section 7.1 Bill of Materials

Part Description	Manufacturer	Supplier	Part Number	Cost Each	Quantity	Total Cost
Base plate	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-001	$200.00	1	$200.00
Linear actuator	Parker	Parker	406XR	$1,200.00	1	$1,200.00
Pin array support plate	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-002	$200.00	1	$200.00
Pin array bottom	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-003	$50.00	2	$100.00
Pin array top	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-004	$50.00	2	$100.00
Pin array circuit	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-005	$30.00	2	$60.00
Pin array circuit backing card	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-006	$50.00	2	$100.00
Pin array end	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-007	$20.00	4	$80.00
Four plug body	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-008	$150.00	2	$300.00
Three plug body	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-009	$100.00	2	$200.00
Face plate	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-010	$40.00	14	$560.00
Pin	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-011	$15.00	100	$1,500.00
Spring	Stamets Tool & Engineering	Stamets Tool & Engineering	PCT022-001-012	$1.17	150	$175.50
Enclosure	Hoffman	Kendall Electric Inc	CSD423612	$615.76	1	$615.76
Power Supply 4A 5V	Allen Bradley	Kendall Electric Inc	1769-PA4	$413.10	1	$413.10
16 IN Sink/Source	Allen Bradley	Kendall Electric Inc	1769-IQ16	$219.60	4	$878.40
16 OUT Source	Allen Bradley	Kendall Electric Inc	1769-OB16	$287.10	4	$1,148.40
CompactLogix PLC	Allen Bradley	Kendall Electric Inc	1769-L35E	$3,330.00	1	$3,330.00
Scanner	Allen Bradley	Kendall Electric Inc	1769-SDN	$775.80	1	$775.80
Control Relay	Allen Bradley	Kendall Electric Inc	700-MB400A1S	$50.40	1	$50.40
Wire Box	Hoffman	Kendall Electric Inc	A1412CH	$110.84	1	$110.84
Emergency Stop Button	Allen Bradley	Kendall Electric Inc	800FP-MT44	$33.37	1	$33.37
Contact Pushbutton Switch	Allen Bradley	Kendall Electric Inc	800E3X10V	$16.37	1	$16.37
Mounting Latch	Allen Bradley	Kendall Electric Inc	800E-A3L	$5.50	1	$5.50
Illuminated Push Button	Allen Bradley	Kendall Electric Inc	800FP-LF5	$14.06	1	$14.06
Touch Screen	Parker	Parker	CTC	$700.00	1	$180.00
Opto-touch button	Banner	Banner	STBVP6	$118.00	1	$118.00
Light curtain	Banner	Banner	EZ-SCREEN	$1,000.00	1	$1,000.00
Dowel Pins		McMaster		$0.25	14	$3.50
Screws		McMaster		$0.25	50	$12.50
Bushings		McMaster		$0.10	100	$10.00
						$13,491.50

Section 7.2 Cost Analysis

Custom Parts

Parker has an in-house machinist, who makes many of the custom parts needed for testing and manufacturing. However, since the machinist is often busy they have decided that all custom parts will be quoted by three outside machinist companies, so that the best price can be determined. Estimations have been made as to the price of the parts based on past parts Parker has had made by these machinist companies.

Standard Parts

Many of the prices on standard parts have been quoted directly to the students. Parker has stated that the prices they get on many of the electrical components from Kendall electric will be lower than the prices the students were quoted.

Overall Cost

The overall cost to make the electrical cable tester is $13,491.50 which is less than the $15,000 guideline set by Parker. $4,801.50 is to be spent on the mechanical components of the tester, while $8,690.00 is to be spent on electrical components. It should be noted that for some of the parts Parker will be using parts which have already been purchased but are not going to be used for other projects. This will lower the amount of money spent on electrical components for the tester.

Section 8: Conclusion

Section 8.1 Conclusion

The system that is designed is a modular type system which allowed it to be evaluated in 5 separate areas. After initially evaluating the conceptual designs for each area presented previously, it was determined that the tester would be utilizing the Allen Bradley CompactLogix controller, fixed pin array spacing without the use of alignment cards, a spring-loaded pin design, linear actuators for motion, and the click-in style plug holder to fix the plug ends.

This design in its entirety meets the requirements set forth by Parker which include the ability to be trained in less than 30 minutes to operate the machine, like harness change out speed of less than 20 seconds, less than 5 minutes to change machine for testing a different part numbered harness, and the ability to be able to test a 20 conductor harness.

Along with the requirements there are also limitations and constraints that must be met. The final design occupies 9 square feet which falls well under the 15 square feet maximum. The design must also enclose electrical and mechanical parts to act as a safety mechanism to protect the operator. Acrylic panels are adapted around three sides of the machine and a light curtain is positioned where the operator installs the harness to aid in keeping the operator away from the machine as the testing of the harness occurs. Damage to the harness must be considered since the harness will need to be fully functionally after the testing process. The spring-loaded pin design allows for a controlled amount of pressure on the conductor to decrease the chances of damaging the connector or its conductors. The system must allow the ability to add part numbers to the system for new harness designs. The CompactLogix processor chosen is equipped with a 1.5 MB of user memory which is more than enough for this application. Optional flash memory can be added to the system as well. Lastly the final cost is determined to be $13,491.50 which falls within the $15,000 budget. Based on the evaluation of the design requirements, limitations, and constraints it was determined that successfully accommodates the desired solution.

Section 9: References

Section 9.1 References

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[2] Newark Electronics. 4 Sept 2012.
http://www.newark.com/raspberry-pi/raspbrry-modb-512m/model-b-assembled-board-only/dp/43W5302?ref=lookahead

[3] Mouser Electronics. 10 Sept 2012.
http://www.mouser.com

[4] Allen Bradley/Rockwell Automation. 7 Sept 2012.
http://www.ab.com

[5] Parker Daedel. 10 Oct 2012.
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